RAILWAYS AND LOCOMOTIVES

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

RAILWAYS AND LOCOMOTIVES

LECTURES DELIVERED AT THE SCHOOL OF
MILITARY ENGINEERING AT
CHATHAM IN 1877

BY

JOHN WOLFE BARRY, M.Inst.C.E.

AND

FREDERICK J. BRAMWELL, F.R.S., M.Inst.C.E.

LONDON
LONGMANS, GREEN, AND CO.
1882

PREFACE.

The Lectures which form this volume were delivered in 1877 at Chatham to the students of the School of Military Engineering, with the aid of explanatory diagrams and models, which are to a great extent represented by the woodcuts. Those Lectures which relate to Railways were delivered by Mr. J. W. Barry, and those which relate to Locomotives by Mr. F. J. Bramwell, F.R.S.

The Lectures given at Chatham are usually printed for private circulation among members of the Corps of Royal Engineers; but it was thought that the publication of the present Lectures in one volume might furnish a useful book for the general public, as well as for those who have passed through the Chatham course of study.

It is right to observe that portions of three out of six of Mr. Barry's Lectures are extracts from his text-book on Railway Appliances, published about a year before the Lectures were delivered. Mr. Barry found, in pre-

paring his Lectures, that, it being necessary to describe somewhat tersely the details of a variety of railway appliances, he could not do so better or more succinctly than in the words of his text-book, with such further words of explanation as seemed at the time of lecturing to be necessary. He therefore (with the concurrence of the authorities at Chatham) employed almost the *ipsissima verba* of his text-book, where they seemed appropriate to the subject-matter; and the result in the present volume is (as has been above stated) that a considerable portion of the descriptive parts of three of Mr. BARRY'S Lectures is more or less a reprint of an already published book. The remainder of Mr. BARRY'S Lectures and the whole of Mr. BRAMWELL'S Lectures are altogether new matter.

CONTENTS.

SIX LECTURES ON RAILWAYS.

LECTURE I.

LECTURE II.

LECTURE III.

LECTURE IV.

LECTURE II.

LECTURE III.

SIX LECTURES

ON

RAILWAYS

DELIVERED AT

THE SCHOOL OF MILITARY ENGINEERING, CHATHAM

Feb. 1st, 8th, 15th, 22nd, and March 1st and 8th, 1877

BY JOHN WOLFE BARRY, M. INST. C.E.

RAILWAYS AND LOCOMOTIVES.

LECTURE I.

CIVIL AND MILITARY ENGINEERING—RAILWAY CONVEYANCE—WATER CARRIAGE—TRACTION—FIRST COST OF WORKS—GRADIENTS—CURVES—LAYING OUT RAILWAYS—EARTHWORKS—FLOODS—JUNCTIONS.

In commencing this series of lectures on Railways I feel myself under considerable difficulty. The subject is so large, and embraces such a quantity and variety of matter, that it is not easy to make a selection that will be of interest and utility to military men, and will also come legitimately and usefully within the scope of a lecture from a civil engineer to those who are studying their profession in all its branches here. On the one hand I fear I may omit subjects which might with advantage be included, and on the other hand I fear I may include subjects which are already trite.

In many matters the work of a military engineer is almost identical with that of a civil engineer. This is the case particularly with those earth-works and structures of brick, stone, or iron which belong to fortification. In erecting and maintaining, and even in destroying, these works, you have to deal with the same forces of nature as we have to consider in the construction of railways, buildings, or docks.

The circumstance that many, perhaps the greater number, of the leading features of railway construction are embraced in the course of study essential to your profession, alone makes it possible for me to hope to set forth in six lectures the outlines of the subject which I have undertaken to bring before you. Knowing that your course of study here will instruct you in the general principles of constructive engineering, on which the earth-works, bridges, viaducts, tunnels, and other structures of all railways are designed and executed, I have discarded the notion of entering into the details of those subjects, and propose to apply myself to discussing the matters which specially belong to the laying out, the maintaining, and the working of a railway.

A reason, if one were necessary, for the present course of lectures, is to be found in the number of civil appointments connected with railways which, either in this country, or in India, or in our colonial empire, are filled with so much distinction by members of your corps.

A further and perhaps more important reason exists in the bearing of railways upon military operations. No one can have followed the course of modern warfare without seeing of how great importance a knowledge of many such matters of detail must be to the Royal Engineers. It is scarcely necessary here to enlarge on this subject, or to urge how essential it is that such matters should form part of the course of study of a military engineer. It is evident that at some of those crises which occur in war, such special knowledge may be of paramount importance. Indeed the ability of an engineer officer to construct, or to reopen with rapidity, the essential parts of a railway, and some acquaintance on his part with railway working, or the possession of some apparently unimportant technical knowledge of the various

modes of evading, surmounting, or counteracting a railway difficulty (which would perhaps be at the finger ends of a railway engineer or foreman), may make the difference of a town or army being victualled or not, or of a body of troops being transported to their destination or left behind, and so may alter the fortunes of a campaign.

To attempt to forecast all the difficulties that you may have to overcome, in emergencies such as those to which I have referred, or to endeavour to suggest to you all the means which are available for grappling with each of them, would be an endless and a mistaken task. I shall best effect my purpose by putting before you those special features of railway construction which are not mere matters of applied mechanics, and by describing, as well as I can within the limits at my disposal, the mode in which railways for civil and commercial purposes are laid out, constructed, and worked. I shall also at the conclusion of the course refer briefly to some of the methods which in ordinary railway working are employed in dealing with various emergencies or mishaps.

I propose, then, to take in order the questions that arise for consideration in regard to the laying out and the construction of a railway; and of these the first point to be considered is undoubtedly whether in any given case it is or is not desirable to construct a railway at all. Do not suppose that I am beginning outside the reasonable limits of the subject. Any one of you may some day have to determine whether it is best to substitute a railway for, or to add a railway to, the existing means of conveyance by the roads of a country, or whether water carriage in some form or other ought not rather to be maintained, improved, or introduced.

Let us, therefore, consider some of the salient features

of the comparison between railways and other modes of conveyance.

It is almost impossible to do justice to the magnitude of the results which have been attained in the improvements of locomotion since the introduction of railways. We have it brought oftentimes prominently before us by the literature of fifty years ago, when the speed of a well-appointed fast coach seemed perfection. But I would call your attention to the fact that the contrast between an average speed of nearly eleven miles an hour by the Quicksilver or any other of the favourite coaches of the last generation on a long journey over excellent turnpike roads, and the forty-five miles an hour average speed of our express trains on first-class railways, is as nothing to the contrast between the travelling of fifty years ago in Russia, South America, India, or any of those formerly almost roadless countries, and the twenty or twenty-five miles an hour average speed on the railways which have been constructed of late years in those localities. In England and in Western Europe the introduction of railways meant an improvement, certainly great, but after all, an improvement of degree; in other countries, such as those which I have mentioned, it meant a difference of kind, through which many places became accessible which were formerly practically inaccessible, and produce which was formerly worthless by reason of the want of means of locomotion became of value.

In this country the materials for road-making are so easily obtained, and we are always within so short a distance from the sea, that no place can be very inaccessible, even for the free interchange of heavy merchandise or minerals, and one must go to other countries to appreciate the changes introduced by railways. It

was lately my lot to go to the River Plate States of the Argentine Republic for the purpose of laying out a railway; and there the difference between railways and no railways is immense, and such as I have alluded to above as being not a difference of degree but of kind. In that great rolling plain, formed entirely of alluvial deposit, there is no gravel or stone fit for metalling, and it is in fact impossible to make a road which will be passable, after a week's heavy rain, for carts or even for bullock waggons. In winter goods traffic is almost entirely suspended, and it is no uncommon thing for a waggon, drawn by twenty oxen, in fairly good weather, to occupy months on a journey of 150 or 200 miles, while for passengers, even in the most favourable weather, the only means of travelling is in waggons or on horseback. The contrast between such a state of things and the convenience of the slowest railway is greater than anything we know of in Europe, except, perhaps, in the remote parts of Russia.

In some countries, then, a railway competes with good roads, and it is a mere matter of expense or convenience whether goods and passengers be carried on the road or on the railway, whereas in other countries the railway may be said to be without any competitor, for unless goods be conveyed by the railway they cannot at many seasons of the year be transported at all.

Another rival to traffic by railway to be considered is, as I have said, water carriage. Water carriage includes carriage by sea, by rivers, and by canals. Broadly speaking, it may, I think, be stated that for long distances, where the expense of loading and unloading the ships and the expenditure on port dues are small compared with the total cost of a voyage, railways cannot in the conveyance of heavy goods or minerals compete in

cheapness with carriage either by sea or by tidal rivers.

Carriage by non-tidal rivers is another thing. In that case the delays of making a round voyage, that is to say of going and returning, a process which involves the accomplishment of half the distance against stream, often occupy so much time or the expenditure of so much power, that railways may compete more or less successfully with such rivers in the comparative cost of carriage. In all such matters it is almost superfluous to say that no general law can be laid down. A river may be particularly easy of navigation, the stream to be encountered may be slight, the prevailing wind may be up stream, or the river may be wide enough to permit of convenient beating to windward, and under such circumstances river navigation may in cheapness surpass the railroad. In other cases all the circumstances may be adverse to river navigation. Speaking generally, however, on large rivers navigation will be found for low speeds and for considerable distances as cheap, if not cheaper, than carriage by railroad.

But mere cheapness in the cost of the journey is not the only point to be considered. Regularity and certainty of despatch and delivery for most sorts of merchandise, are in many localities of very high importance, and neither of these can be sufficiently attained in sea or river navigation. It may well happen, as it often has happened, that sea and river navigation have been beaten in competition by a railway service from this cause alone, and we see a striking example of this in the large and increasing amount of land-borne coal which comes to London. No doubt much can be done to reduce the uncertainty of the duration of sea and river voyages by the employment of steam power in ships of high class, and we

see instances of this improvement in the fine screw colliers and trading vessels which run with great regularity between the northern ports and the Thames. Other examples will occur to you in the well-found and well-engined ships of the packet lines and in the great river steamers of the Continent and America. But still, when all that can be done has been done to ensure regularity, there remains a formidable and proverbial uncertainty in both sea and river navigation, which, *pro tanto*, places it at a disadvantage with a railroad service. A further and important circumstance telling in favour of a railway service is the facility it affords for the distribution and collection of the traffic at different spots often at a considerable distance from each other. A train of trucks can be broken up into as many units as there are trucks, and each truck can be sent separately to its destination; but this is very different from the case of a vessel containing 1,000 or 1,500 tons of cargo, which cannot, as a rule, be all used or stored at the point of disembarkation and has to be sent to many different customers.

Canal navigation is in this and in many other respects different. In the first place, with regard to cheapness, the proprietors of the canal having spent capital in making the canal, and in many cases expensive storage reservoirs, to provide for the waste of water in lockage, are not only subject to a yearly outgoing for renewal and maintenance and management of the works, but have also, if possible, to provide interest on the capital expended. The working expenses and interest result in the imposition of tolls more or less heavy. The wind cannot be much used as a power for locomotion in a canal, and it becomes necessary to incur the cost of employing animal or steam power. On the other hand, much thought has been given to enable both

animal and steam power to be applied to the best advantage on canals, and the consequence is that after meeting the above-named expenses the cost per ton of heavy goods conveyed by canal is remarkably low; so low, indeed, that it is a moot point whether we in this country have not been over hasty in discontinuing to a great extent the use of our canals, and whether much of the mineral traffic which now encumbers the main trunk lines of railway might not advantageously be conveyed as formerly by canal. There can be no doubt that much might yet be done to improve the conduct of canal traffic, to apply power still more cheaply, and to overcome one of its great drawbacks, viz. the waste of water in lockage.

In canal navigation properly conducted, and in temperate climates, there ought to be as a rule little of that uncertainty in the duration of a voyage to which sea and river navigation is exposed, and a railway ought not to be able to claim much advantage as compared with a canal in regularity of despatch and delivery. Frost is, however, a difficulty which is serious, and even in this country our canals are occasionally in hard winters useless for weeks together. But making allowance for all these drawbacks, it cannot be denied that canals properly conducted are for heavy goods most valuable means of locomotion, and in some countries offer peculiar advantages. I ought not to leave this branch of the subject without pointing out that there are cases where canals may be with advantage used for the two purposes of locomotion and irrigation, and it may be that this fact may in certain cases give a canal the preference over a railway.

All the above-mentioned means of water carriage enter so sharply into competition with railways in cheapness for slow traffic, that they must receive due con-

sideration in judging whether for such traffic a railway should be built. But the case is very different where an important passenger traffic has to be accommodated and where high rates of speed are required either for passengers or for perishable goods. Here the railway is among all known means of locomotion pre-eminent.

Let us now consider the contrast between carriage by railway and carriage by road. Here, omitting the element of first cost, cheapness of transit will undoubtedly be found on the side of the railway. To move a load on the best roadway vehicle along a level and smooth macadamised road requires the expenditure of a steady force of from forty-four to sixty-seven pounds per ton. To drag a similar load along a straight smooth line of railway at ten miles an hour requires but about eight or

TABLE No. 1.—TRACTION ON ROADS.

RESISTANCE IN LBS. PER TON ON LEVEL ROADS OF DIFFERENT MATERIALS.

Stone tramway	20 lbs. per ton.
Paved roads	33 " "
Macadamised roads	44 to 67 " "
Gravel	150 " "
Soft sandy and gravelly ground	210 " "

TABLE No. 2.—TRACTION ON RAILWAYS.

RESISTANCE ON A STRAIGHT AND LEVEL RAILWAY OF TRAINS OF ORDINARY DESCRIPTION AND WEIGHT.

Velocity of train in miles per hour	10	15	20	30	40	50	60	70
Resistance in lbs. per ton	8½	9¼	10¼	13¼	17¼	22½	29	36½

nine pounds per ton. In Tables No. 1 and No. 2 are given from the ordinary text-books the tractive forces necessary under different conditions of the material forming the road as compared with the tractive force required on a straight and level railway. We thus see that on a

railroad the resistance even at 60 miles an hour does not exceed 29 lbs. per ton, and we must remember that in this resistance are included the very considerable retarding forces caused by the resistance of the air, by the various elements of friction between the carriages and the rails, and by the friction of the several parts of the carriage itself, all of which are aggravated by travelling at such a high velocity.[1]

From the above considerations of the resistance to traction in the two cases of road and railway, there can be no fear of road traffic being a competitor in cheapness of working with a railway when made, and we may also be sure that for passenger traffic and for goods requiring to be conveyed not only with regularity, but also at a tolerably high rate of speed, water carriage can scarcely compete on anything like equal terms.

Roads being cheap in first cost, may, with light traffic, pay better than a railway, and the circumstances of the traffic to be accommodated may not justify the cost of a railway. One of the most important services of roads in poor countries is often to act as feeders to a main line of railway, which may perhaps as a trunk line pay well in itself but could not support the cost of branches on which the traffic is too small to be remunerative.

Tractive force by means of steam power is likely in the future to be introduced largely on roads, especially where animal power is costly. The road traction engine may be said to be at present in its infancy, and great development of this means of locomotion may be looked for. In viewing this branch of the subject it must be

[1] In the table No. 2 above given, the resistance due to the weight and friction of the engine itself is not included, and the figures simply denote the towing strain exerted on the coupling between the engine and the foremost carriage of a train.

remembered that however economically tractive force may be obtained, the elements of resistance due to imperfections of the roadway will remain and be in all cases much greater than on a railroad.

When these general considerations have been investigated, and if it be decided that a railway is to be constructed, the important question arises in what manner is the railway in question to be laid out. The beau-ideal of an ordinary railway would be one perfectly straight and perfectly level. This would produce economy of time in performing the journey, and of money in the working expenses. I need not say that in most cases such a line is unattainable; and one point on which judgment is required is how far straightness and levelness are to be aimed at, or how much of first cost is allowable in view of the circumstances under which a line will be worked when made. An extra expenditure of 10,000*l.* per mile means that to justify it about 10*l.* per mile per week should be saved thereby in working expenses. In some cases the 10,000*l.* of extra first cost will be amply repaid, but in other cases it may form a heavy burden on the railway for ever, and never be wholly repaid.

Another important consideration is that the railway should be at such levels and so near to the surface as to accommodate the country through which it passes, giving to towns and villages convenient access to its stations. It is of no use to a town that a railway should be made to pass near it if that railway be in a tunnel 100 or 200 feet below it, and it is only of partial utility if it be on a lofty viaduct far above the roads. Thus, the laying out of an ordinary railway is often a matter of compromise between what is desirable and what is attainable. This is particularly the case in hilly countries, or in cases in which railways have to be made cheaply

or made quickly, and in which the construction of works of art, as the French euphemistically call railway bridges, viaducts, and tunnels, has consequently as far as possible to be avoided. Frequently from an engineering point of view a long tunnel or viaduct may be extremely desirable, but on examination may turn out to be financially inadmissible. Again, it may be that in the case in point the yearly returns might pay for the first cost of important works of art, but the expenditure of time necessary to construct them cannot be afforded. The above matters are of particular interest in remote countries, where structures such as tunnels, viaducts, and bridges are often the crucial points of the questions (1) whether a railway can or cannot be made, and (2) what time will be occupied in making it.

In military and temporary railways time is the essential point, and economy, either of first cost or of working, is of no consequence. I allude to railways undertaken in war time, such as those constructed by ourselves at Balaclava, and in Abyssinia, or by the Germans to avoid the fortresses of Metz and Tours, or to such temporary lines as may be required to avoid or repair a gap made by the enemy in a railway. In such cases economy of money is nothing, but economy of time in constructing the railway is everything, and any works of construction that cannot be rapidly put together and cannot be made of materials readily accessible, must be rigorously eschewed.

Having come to some conclusion on the limitations which the case imposes, with respect to the first cost which may be properly incurred on a railway, and with respect also to the employment of costly and delay-causing works, the problem which presents itself is to lay out as good a railway as is possible after weighing all the requirements of the case under consideration.

It is perhaps needless to say that if we cannot make a straight and level railway from point to point, the direction and level of the railway are determined by the question of the permissible gradients on the line. We may have to go over a range of hills or to descend and cross a river, but in either case we shall probably have to say what is the steepest gradient which, under the circumstances, we must aim at not exceeding, in any part of the line in question.

Now, without trenching on the province of my friend Mr. Bramwell, who will doubtless indicate to you the available tractive force of the locomotive engine, I may remind you that there is a maximum tractive force that a single ordinary locomotive can apply; and assuming any given load as the maximum for any train, we can, if we look only to the loads to be conveyed, say what is the steepest gradient that can be tolerated.

The class of traffic, however, that seems to demand the easiest gradients is that of minerals to be carried at an economically low speed. In this case almost any gradient against the load is prejudicial, and the only hope of carrying minerals over long distances in successful competition (so far as cost of transit is concerned) with water carriage is to have the heaviest possible trains drawn by a single locomotive.

But there are many other matters to be borne in mind besides the question of making a line which can be worked very cheaply, and, having considered the country, we must cut our coat according to our cloth. Knowing the class of line he is endeavouring to lay out, an engineer, if it be a local line, to serve an agricultural district, will content himself, if necessary, with gradients of 1 in 60, 1 in 50, or even 1 in 40, on a line where few trains will run, and where the saving in interest on first cost

will pay for some extra expenditure in locomotive power.

If, however, a line be required for high-speed passenger traffic, other points have to be considered. To creep slowly up hills, and to rush down them, is a policy that has its limits. It is not only wasteful in expenditure of locomotive power, but in the wear and tear of both rolling stock and permanent way, and, with regard to this last item, very steep gradients for high speeds involve, or ought to involve, greater first cost in the permanent way. Safety and the necessity of being able to pull up within a reasonable distance, limit the speed in running down hill, so that we may say that for high-speed passenger lines even occasional gradients steeper than 1 in 100 should be avoided if possible; and for very high-speed passenger traffic there is no doubt that still easier gradients are important. In both cases a few steep gradients do less harm than a generally rather heavy line.

One of the first considerations is, therefore, the ruling gradient to be adopted. A ruling gradient is the steepest gradient on any railway or portion of a railway under consideration, and probably takes its name from the fact that it determines the weight of the trains. A railway may, however, be divided into sections with different ruling gradients, and in that case the mode of working one section may be, and often is, different from the mode of working the other sections. Having settled what ruling gradient is desirable for working the traffic on the whole line or on the section under consideration, we should carefully investigate what is the gradient which nature prescribes to us in the country through which the railway is to pass. For instance, in a certain district a gradient of 1 in 70 may be one which can be adjusted with facility to the slopes of the hills, so as to give us a railway almost on the

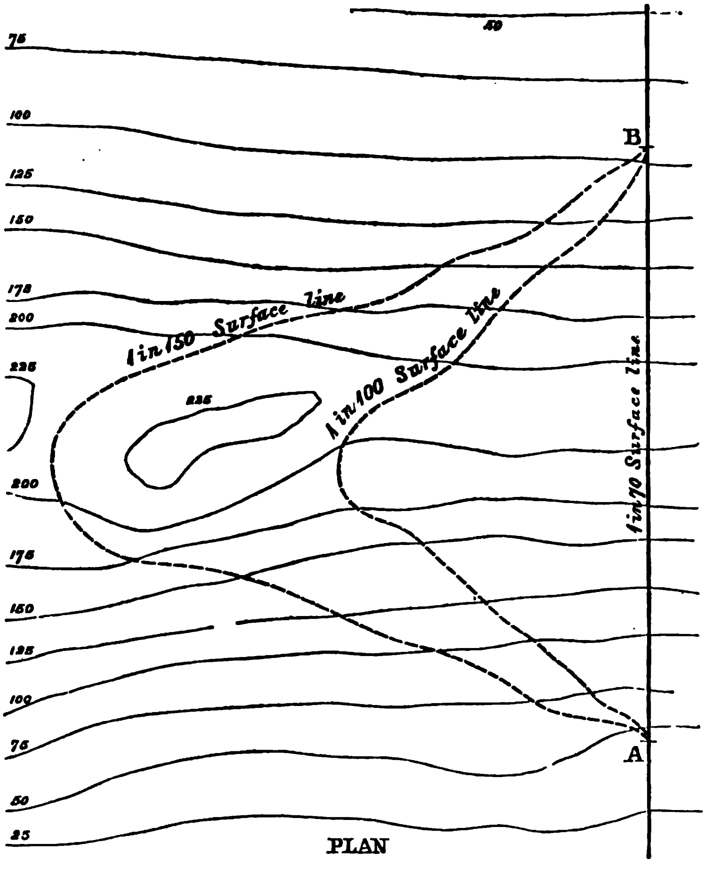

75
100
125
150
175
200
225
200
175
150
125
100
75
50
25
50
225
B
A
1 in 150 Surface line
1 in 100 Surface line
1 in 70 Surface line
PLAN

Fig. 1.

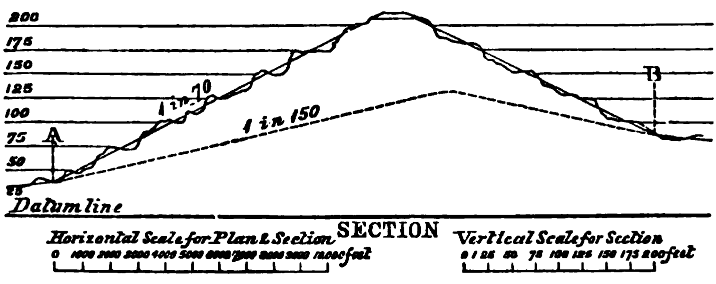

200
175
150
125
100
75
50
25
A
B
1 in 70
1 in 150
Datum line
SECTION
Horizontal Scale for Plan & Section
Vertical Scale for Section

Fig 2.

surface of the ground, whereas a gradient of 1 in 100 will involve a complete change in the nature of the works, and will cause a large expenditure in cuttings and embankments, in tunnels and viaducts.

Fig. 1 illustrates my meaning; on it are drawn 25 feet contour lines, and two imaginary towns are indicated by the letters A and B. We will suppose that the full black line shows the direction which the railway ought to follow, as the shortest distance between A and B. If the ruling gradient adopted be such that the railway will rise at least 25 feet in the distance between the intersections of the full black line and the contour lines, the railway will be a surface line. Thus, if the 25 feet contour lines be not less than 1,750 feet apart, measured along the line of railway, the ruling gradient of the direct line as a surface line would be 1 in 70. But suppose we adopt a gradient of 1 in 100 or of 1 in 150? Then, unless we alter the angle at which the railway crosses the contour lines, and deviate it from its proper direction, along one or the other of the two dotted lines, as shown in fig. 1, the railway will gradually bring itself deeper and deeper at each contour line, and, instead of being at the surface, will at the last contour line be deep below the level of the ground. In fig. 2 is shown a section of the railway in two of the cases just mentioned. In the one case a gradient of 1 in 70, and in the other case a gradient of 1 in 150, has been adopted on the straight line, and it will be seen that in the latter case the line will be 90 feet below the top of the hill.

There are situations where a line can be deviated, as above referred to, without corresponding disadvantages, but there are other cases where to do this will be to gain the advantages too dearly, and where it is better boldly to face the difficulties of the direct line.

It is in many cases clearly right to disregard all notions of making a surface line: for instance, where the saving in working expenses is certain to fully repay the cost of expensive earthworks, tunnels, and viaducts. It must, however, be remembered that the interest on the additional first cost is a charge which cannot possibly be evaded; it is a constant quantity and has to be faced, whether the traffic be great or small, and no improvements of locomotives or rolling stock, or in modes of working, can ever lessen that item of charge.

While flat gradients are unquestionably most desirable, the time has gone by when it was thought that, unless at least as good a gradient as 1 in 300 could be attained (which was chosen as being at that time considered to be the steepest gradient on which vehicles would not begin to roll from their own weight), it was useless to attempt to make a successful railway. Now-a-days, thanks to a great extent to the improvements which have taken place in the locomotive, we see all round us examples of steep and yet financially successful railways; and though we may all wish for a flat line, it is apparent that there are even more important considerations involved, and that, in this respect as in others, we may buy gold too dear.

Bearing these matters in view, our endeavour should be to get the best gradients we can for our money; and by the 'best gradients' I mean those best adapted for the traffic to be expected on the line. Thus, for a railway, on which the bulk of the traffic will be passenger traffic, the load will be much the same in both directions, because passengers pass and repass in about equal numbers between any two places, though it may be that at certain times of the year or of the day the stream of passengers will be more strong in one direction than in the other. Even were

there no such equality, the small proportion which the weight of the passengers even in a fully-loaded passenger carriage bears to the weight of the empty carriage makes the question of the direction of the traffic comparatively unimportant. In passenger trains from 70 to 80 per cent. of the total load consists of the weight of the passenger carriages, even when all the seats are occupied. Therefore for a passenger line the steepest admissible gradient may be used in either direction. But for goods and mineral traffic the case is different, for in goods and mineral trains only about 30 to 50 per cent. of the total load consists of the weight of the vehicles, and on goods and mineral lines the flow of traffic is often entirely in one direction. In such cases money ought to be spent freely for securing good gradients where opposed to the loaded trains, while we may be content with worse gradients where these are merely opposed to the returning empty trains. Many of the lines connecting the collieries with shipping ports are examples of lines with falling gradients for the loaded trains, and in such cases the locomotive power is only called upon for bringing back the empty trucks.

In some colliery lines we find that the gradients with the load are matters about which there is but little choice, as the lines descend mountain valleys more or less steep, and have to conform to the general slope of these valleys. In laying out the parts of the line where there must be gradients against the load, we may have more choice; and in determining the ruling gradient against the load on such parts of the line, we should consider the traction on the ruling gradient against the returning empty trains, and endeavour to make the ruling gradient against the full trains suitable to the amount of tractive force which must of necessity be available for bringing back the empty trains. To give an example of my mean-

ing. With the best mineral trucks, the weight of the waggon when empty is about 30 per cent. of the weight of the waggon loaded, and thus an engine that will drag itself and a train of empty trucks up 1 in 50 will be able to drag the same number of full trucks up an incline of 1 in 170. If, therefore, the circumstances of the country compel the adoption of a gradient of 1 in 50, descending with the load, we must endeavour to have no steeper gradient than 1 in 170 against the load if we desire to take full advantage of the power of the locomotive both in going and returning.

It may happen that it is possible to adopt a good ruling gradient for the greater part of a railway, and that it is only necessary to use a steep ruling gradient at one or more particular spots. A concentration of steep gradients at one place or in one district is more economical in working the traffic than steep gradients scattered, so to speak, over the whole line; for special means, such as additional engines, engines of special construction, or fixed winding engines, may be locally employed for forwarding the traffic over the steep gradients, and the traffic at other places may be conveyed without these special appliances. This cannot happen if steep gradients are intermingled with easy gradients, and in such cases the power employed must be adequate to surmounting the steep gradients, and will be working wastefully over the easy gradients. Examples of the former mode of laying out railways are to be seen in some of our colliery lines, on which the ruling gradient of the greater part of the railway is flat, except near the collieries. In many such instances fixed engines and ropes are used to drag the vehicles up the steep inclines, or else the train is split up and hauled up the inclines in detail by an ordinary or by a special locomotive.

The same considerations of first cost have to be borne in mind in dealing with the question of curves on railways. The curve of minimum radius to be adopted in many cases is, like that of the ruling gradient, a com-

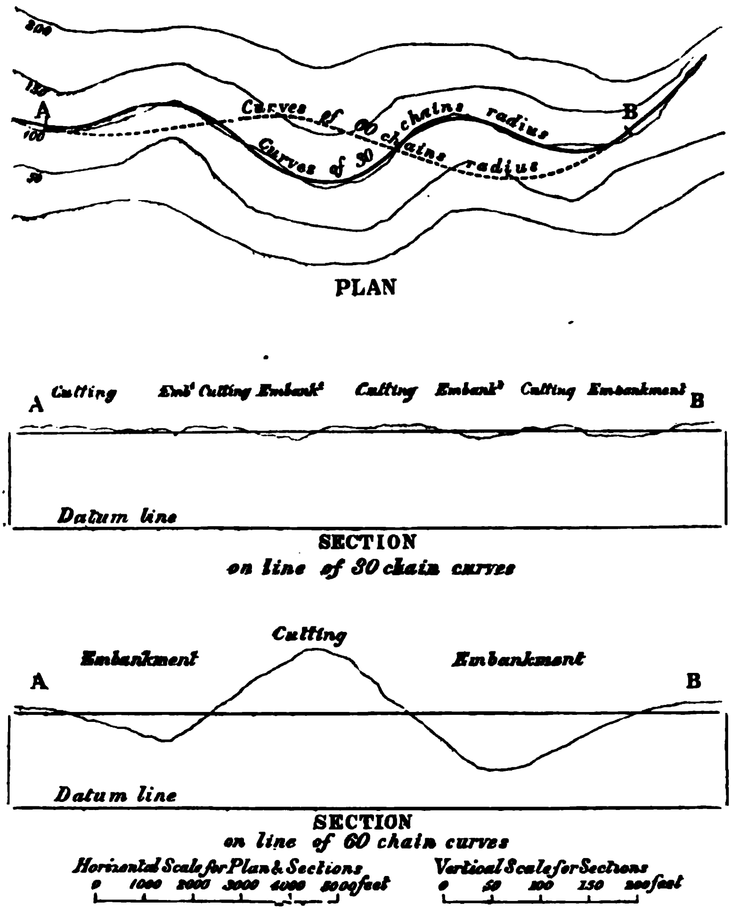


FIG. 3.

pound question, into which enters the consideration of safety, convenience, and economy of working, in antagonism to the question of expenditure in the cost of

construction. Two desiderata of a railway are, as has been said, levelness and straightness, and in some well-known examples these seem to have been very nearly attained. In many of the early railways in this and other countries any curves of less than a mile radius were almost forbidden, except at junctions or stations, where the speed was expected to be at all times low. The early railways were generally constructed on favourable ground along main valleys; but as railways were required in parts of the country not approached by the main valleys, it was found necessary to adopt curves of much smaller radius, in order that the railway might be made to conform to the general features of the ground. Thus, in laying out an economical railway on the slopes of side-lying ground, one has, if possible, to adopt such a curve as will allow the railway to hug the hill side where necessary; for unless this can be done, the line of railway will be constantly leaving or entering the hill side, and very heavy embankments and cuttings will be necessary. An example is given in fig. 3 of the difference of using a curve of 30 chains and a curve of 60 chains radius, on the sides of a valley, the section being given in each case. In this example it is assumed that the position of the points A and B are prescribed, as also are the directions of the straight lines which approach the points A and B before the curves commence.

The minimum curve that may be adopted under different circumstances, and apart from the matters above mentioned, is a question involving several considerations, which cannot be adequately viewed, until we have considered many other matters of railway construction, which will be treated of in subsequent lectures. In modern practice, curves of from 30 to 40 chains radius are often introduced on high-speed passenger lines.

Curves of 15 and 12 chains are used in exceptional places on passenger lines, and still smaller curves on Metropolitan lines and in stations, and in sidings. The curves approaching Cannon Street Railway Bridge are 8 chains radius, and the curves of the lines joining the Metropolitan Railway to the Great Northern Railway are $6\frac{2}{3}$ chains radius.

Much sharper curves are introduced on special lines. A well-known example of what can be done in the way of accommodating a railway to the contour lines of a hilly district is the Festiniog Railway in Wales, on which the gauge is only 2 feet and the curves of minimum radius are about 2 chains. If it had been necessary on this railway to use the ordinary narrow gauge of this country, viz. $4' \; 8\frac{1}{2}''$, with a curve of the usual minimum radius of say 10 chains, the line would have required works of such magnitude as to preclude the financial possibility of having a railway in the locality. It is, however, but rarely that the question of the gauge affects the other considerations which define the curve of minimum radius. Usually the natural features of a country are such that curves permissible for other reasons will accommodate themselves sufficiently easily to the sides of the hills.

When the general direction of a railway has been decided on with reference to the matters above referred to, then, unless in cases where a map of large scale already exists, a rough survey is made, and what are called trial levels and trial sections are taken, in order to determine with greater precision the direction of the railway from point to point. The question of how far we can follow the general direction prescribed to us, so far as it depends on the physical features of the country, generally resolves itself into the question how the railway is to cross a ridge

of hills or a valley. These points, therefore, are those which first require detailed study, and, as a preliminary to further operations, the height and width of the ridge or the depth and width of the valley at various points have to be determined.

Thus, in the case of a ridge we desire to find a de-

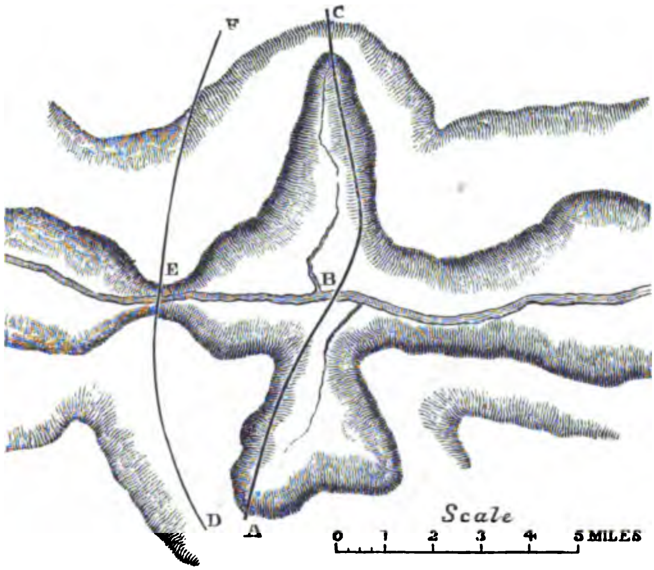


FIG. 4.

pression which is low enough and is approached by acclivities sufficiently gentle to allow of their being traversed by the ruling gradient. If it be impossible to avoid a tunnel or very deep cutting, some other point on the ridge may perhaps be found, which, though higher in level, may be less in width, or which can be approached with easier gradients up to the spot where a tunnel must be made; for if a tunnel of given length has to be made, it is not a material point whether the hill above it be high or low. Thus, if we assume the length of a tunnel to be a fixed

quantity, it becomes a question where we can apply this

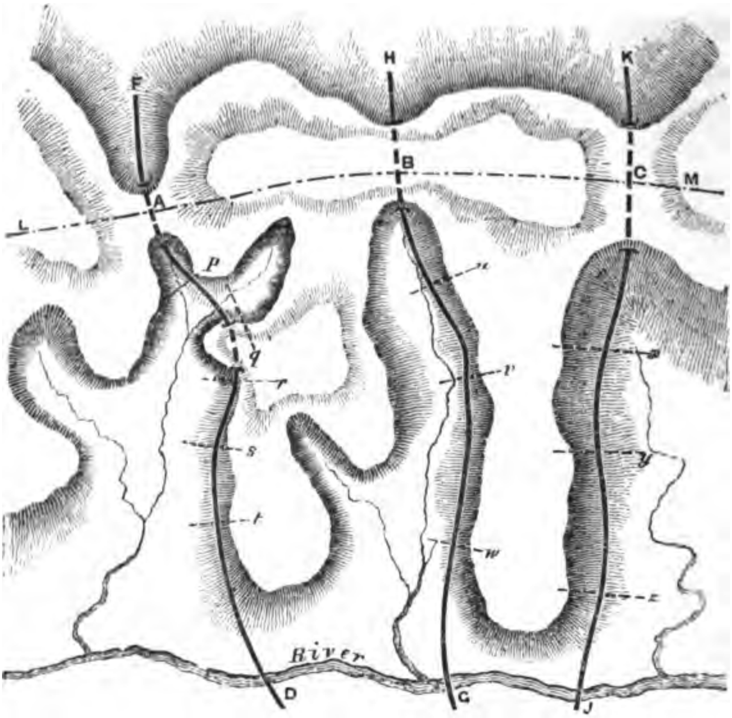


FIG. 5.

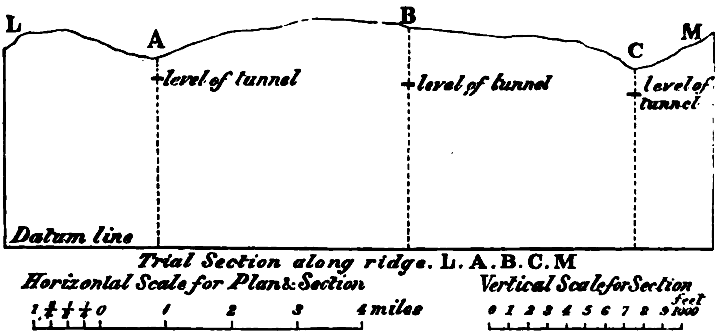


FIG. 6.

amount of tunnel to the best advantage. Examples of

such cases are given in the figs. 5, 6, and 7, to which I shall refer again presently.

Conversely in the case of crossing a main valley, the question is whether it is best to look out for a place where, by taking advantage of cross valleys, the line may be led

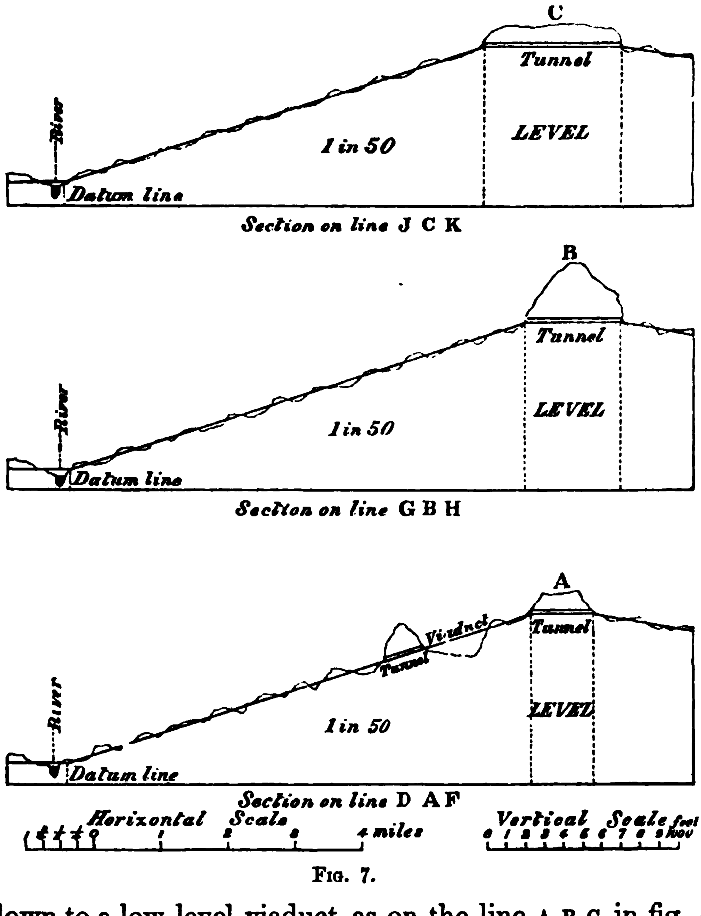


FIG. 7.

down to a low level viaduct, as on the line A B C in fig. 4, or whether there is any point where, the sides of the valley approaching each other, the line can with greater economy be carried across it on a high level with a more

lofty viaduct, as on the line D E F. The case of a viaduct is, however, not exactly comparable to that of a tunnel, as a high viaduct costs considerably more than a low one.

Taking, then, the case of a ridge, and returning to the figs. 5, 6, and 7; an examination of the apparently available points of crossing it, with perhaps a line of levels taken along the ridge, as shown in plan by the dotted line L A B C M on fig. 5, and in section on fig. 6, nearly at right angles to the line of the proposed railway, will indicate whether one or more points of crossing require further examination. Then rough trial sections, along lines such as those indicated on the plan by the lines D A F, G B H, J C K, on fig. 5, following approximately the lines a railway could take, and a few cross sections at critical places shown by the short dotted lines (*p. q. r. s.*, &c.) on fig. 5, may be made on each of the possible routes. These trial sections will aid a further examination of the ground on each route, and such an examination will probably indicate definitely which is the best line to follow.

Of two routes the trial sections may appear equally good, in the general question of how best to cross the ridge, but on one line there may evidently be greater facilities than on the other for still further improving the line in the main valley leading up to the ridge; the hills on either side may be less intersected with cross valleys, and the main valley may have more regularly sloping sides, showing that a little further care in selection of suitable ground on one of the routes will enable a good line to be laid out, which might on the other route be evidently unattainable.

A further reference to figs. 5, 6, and 7 will explain more fully the point to which I have been alluding. The line J C K approaches the hills by a gradient of 1 in 50, but cannot pass the ridge L A B C M without a tunnel about

two miles in length about 100 feet below the surface of the ridge at the point C. Whereas, by adopting the line G B H with the same gradient the ridge can be pierced at B by a tunnel only 1¼ mile long, but at a much greater depth. Again, the line D A F can cross the ridge with a still shorter tunnel, but the valley up which the line has to pass is so much broken by cross valleys as to entail expensive work. In these cases the line G B H is the one which should be adopted.

Having, by some such preliminary examination, determined the general course of the line, the next step is to have such a survey prepared of the leading features of the ground as will enable the line to be laid out with accuracy. This survey should be wide enough to allow of shifting the line considerably on either side of the probable direction, and much time and trouble are often saved by making the survey wider than at first seems necessary.

On the rough survey a line is laid down with suitable curves, using the information already obtained as to levels for suiting the line to the contour of the ground. A more careful section is then taken over the ground along the line so laid down on the plan. Cross sections are also taken where it may seem desirable, and by this time it will in all probability be found that a slight shifting of the line one way or the other will give what appears the most suitable line. In finally fixing the line several points have to be considered.

With regard to the plan, it must not be supposed that, because a certain curve has been thought to be the minimum permissible curve, it is wise to follow the contours of the ground as much as such curves will allow. It may be bad policy to carry a line into a broad depression, or so as to follow some deep

but narrow cross valley, where in the one case a moderate embankment, and in the other case a short, if high, viaduct would enable a comparatively straight line to be followed; for the longer line, though running on the surface, may by reason of its greater length cost more than the straighter line; and it must be remembered that any needless lengthening of the line will always entail an unnecessary burden in the expense of working. The additional length has not only to be made in the first place, but has to be kept in repair, and moreover every train will have to run over the additional mileage.

It will sometimes be worthy of consideration whether in crossing a short valley, if it be also not deep, a very short rapid incline both ways is not better than a circuitous but contouring surface line with a more gentle gradient; for unless the total fall be more than 15 or 20 feet, the excess of velocity given to a train by such a depression is not serious, and consequently the velocity gained by the train running down one side may be trusted and may be safely used to carry it up the other side of the depression.

Some of the points which affect the relative cost of works, and are therefore of importance in the laying out of a line, must now be referred to.

It is important so to adjust the levels of the rails that the amount of earth to be excavated from cuttings may balance, or as nearly as possible balance, the amount of earth required to make the embankments. This introduces the subject of the slopes at which earth will stand, and necessitates the investigation of the geological character of the country to be traversed by the railway. In the following table are given the slopes at which earth will stand after lapse of time under ordinary conditions, that is to say, on the supposition that there are no abnormal conditions, such as bad natural drainage or stratification

inclined downward so as to make a launching 'way' on which the earth can slide, nor any admixture of foreign substances with the earth which, on exposure to air or damp, enter into new mechanical and chemical combinations and cause the earth to alter its condition.

Subject to these qualifications the average natural slopes with a horizontal line at which different earths will stand may be taken as shown in Table No. 3.

TABLE No. 3.

	Horizontal.		Vertical.
Gravel	1	to	1
Dry Sand	$1\frac{1}{4}$	„	1
Compact Earth . . .	$1\frac{1}{2}$	„	1
Clay well drained . . .	$1\frac{1}{2}$	„	1
Clay wet	3	„	1

In addition to the above kinds of earth, rock cuttings have often to be considered; and in the description 'rock' we may include chalk as the softest, and granite or gneiss as the hardest. Similarly, the line of demarcation between the other descriptions of earth is anything but well marked; indeed there is no subject on which the judgment of the engineer has to be more carefully exercised than in dealing with the different descriptions of earths and rocks which he encounters, and in deciding on the different slopes to be given to the cuttings and embankments. It must be borne in mind that there are rocks which, though difficult to excavate, disintegrate under the influence of the weather, until eventually they will stand at slopes no steeper than does ordinary earth; and on the other hand some rocks will stand for ever with scarcely any slope at all. In deciding on the slopes of the earthworks an engineer has to steer a middle course between prudence and extravagance of expenditure.

The above-mentioned slopes refer to the slopes at

which the natural earth or rock will stand in the side of an excavation; but in balancing the cuttings and embankments allowance must be made for the difference of angle at which a cutting will stand and that at which an embankment made of the earth from that cutting will stand. Thus we may excavate rock from a cutting and find that the cutting will stand at a slope of $\frac{1}{4}$ to 1 or $\frac{1}{2}$ to 1, but when the loose materials from that cutting are tipped into an embankment the angle of repose of these materials may be $1\frac{1}{4}$ to 1. As a general rule the softer earths will stand at about the same inclination in an embankment as they do in a cutting, but the material from a rock cutting will seldom stand at a steeper angle than $1\frac{1}{4}$ to 1, or in extreme cases 1 to 1. In estimating the slopes of earth on railway works in the absence of special knowledge of the material, $1\frac{1}{2}$ to 1 is an average which it is customary to adopt for cuttings and embankments, and which in practice gives fairly correct general results.

Next, we must not forget that earth excavated from a cutting will not be contained in an embankment of the same cubical dimensions as those of the cutting. The extra space required even after subsidence will vary with the material to be used, from about 8 per cent. in the case of sand, gravel, and clay, to 20 per cent. in the case of broken chalk and rocks.

The earthwork should balance not merely on the whole railway, but as far as possible on each part of it, as otherwise extra expense will be incurred in carrying the excavated material long distances. Thus, as far as possible, the material from each cutting should go into the immediately adjacent embankments.

Trial holes or borings (if trial holes cannot be made) should be made along the line of railway, to give information of the nature of the ground, and it may happen

that the knowledge gained from the borings may render desirable a modification of either the position or level of the railway. The number and position of the trial holes which may be advisable depends on the local circumstances of the line. Thus in districts in which there is a great variety of stratification, one or more trial holes are desirable at every cutting, but in districts of more uniform formation so great a number is unnecessary. In all cases trial holes should be made at the site of all important works, such as viaducts, large bridges, or tunnels. The expense of trial holes will be amply repaid when the works of construction are begun by their enabling thorough consideration to be given beforehand to the details of the works to be undertaken. For instance, if in a cutting rock is likely to be encountered, it is of great importance to an engineer in laying out a railway to know beforehand the actual depth below the surface of the ground at which it will be reached. On this circumstance depends the inclination of the slopes to be given to the sides of the cutting and consequently the width of the cutting at its top, and the amount of property required. For, supposing that in a cutting 40 feet deep, hard rock will be met with at a depth of 20 feet below a surface of ordinary soil, the slopes of the cutting for the upper 20 feet will be probably $1\frac{1}{2}$ to 1, and for the lower 20 feet $\frac{1}{2}$ to 1, whereas, if the whole depth of the cutting were in ordinary soil, the slopes from top to bottom would be $1\frac{1}{2}$ to 1. In the one case the top width of each slope of the cutting will be 40 feet, and in the other case 60 feet. The cubical contents also of the cuttings, and consequently the amount of earth available for embankments, depend on the question of the side slopes, or, in other words, on the soil to be encountered in digging that cutting, and this can only

really be ascertained with any approach to accuracy by sinking trial holes or borings. Borings, though very useful and under some circumstances more convenient than trial holes, are not so trustworthy as good-sized pits which lay bare a considerable area of soil for examination.

The introduction of a tunnel on a railway depends, as a rule, on the question of the cost of a cutting of the depth required to pass through a ridge, as compared with the expense of a tunnel. Thus the first thing to be considered is, what will be the cost per yard of a tunnel through the hill in question, and, when that is known, it is a mere matter of calculation at what depth of cutting it will pay to begin tunnelling. In the case of a double line of railway in ordinary ground it will ordinarily pay to tunnel when otherwise a cutting must be of a depth of 60 feet, but this is only a rough generalisation. In a case which recently came under my notice I found that it paid to tunnel when a depth of 40 feet was reached. The case in question was that of a single line in a tunnel through soft rock.

The question whether to substitute a tunnel for a cutting will depend to some extent on the balance of the earthwork, for if the amount of earthwork in the cuttings, irrespective of the cutting under consideration, be insufficient for the embankments, it will be better to make a deep cutting, although a tunnel might *per se* be cheaper.

The economical introduction of viaducts depends not only on the balance of the cuttings and embankments, but also on the greatest height which it is prudent to adopt for embankments, and this consideration is affected greatly by the nature of the soil. It may be prudent to make a bank 60 feet high, if it is to be made of chalk

or fragments of rock, but it would not be wise to make such a bank of London clay. We should also remember that the question of the relative advantages of an embankment and a viaduct often arises where a railway crosses a main valley in which a stream has in some way to be bridged. A bridge or culvert under a lofty embankment, and large enough to provide for unusual floods, is a very expensive work; and any accident to a culvert beneath a high embankment gives rise to great trouble, and may in some cases destroy the embankment completely. Thus it often happens that in comparing the cost of a viaduct and of a high embankment a large sum of money has to be added to the cost of the embankment to provide for a bridge or culvert sufficient in dimensions and strength.

In constructing a railway in or across valleys, provision must be made for floods, and the level of the line should be kept well above flood level. Every information should be sought for with regard to records of floods, and perhaps the best authority on the subject is, after all, the oldest inhabitant living by the side of the water-courses. His memory is probably a better authority when it goes to the question of the height to which the water has risen in his garden, or kitchen, or bedroom in his time, or in his father's and grandfather's time, than the records of any one else who is not so specially interested. A word of caution is necessary, however, to make sure that the information of the oldest inhabitant extends far enough backward. In the early part of this year we had floods in the Thames valley which were higher than any that have taken place for twenty-five years, but not so high, we know, as those which occurred seventy years ago. An engineer might be tempted to assume that he was taking all necessary pre-

cautions if he provided against the highest flood known in the memory of a man seventy years old; but this is not the case, and greater care has been shown to be necessary even in England, where the rivers are small. In India and other foreign countries this question of floods is one of primary importance, for the rivers met with there are bodies of water by the side of which all our English rivers are insignificant. Only a few months back bridges and viaducts on one of the Indian railways were swept away by floods, the repair of which works will cost upwards of three-quarters of a million. In this and other similar cases no doubt every care was taken to obtain information as to the probable height and current of the rivers in flood time, but very great difficulties are found in acquiring really trustworthy records. Probably there has been a precedent for the floods in India of last year, and, if a record of it could only have been accessible, the disaster might have been avoided.

A prudent engineer will thus not sail too near to the wind in this matter of floods, but will place his line considerably higher than the level of any known flood; will allow an ample water-way for all rivers both before and after they have topped their banks; and will carry the foundations of every structure to a depth below the river bed, which will appear extravagant to any one who only sees the rivers on their good behaviour.

The crossing of roads has to be provided for in laying out a line, and I shall have occasion to refer to the construction of bridges, and the relative advantages of bridges and level crossings.

A few words are necessary here on the subject of laying out junctions of one line of railway with another, though the minutiæ of this matter will be hereafter referred to in detail when the signals come to be considered.

Railway junctions of the ordinary description shown in figs. 8 and 9 should, as far as practicable, be so laid out that an engine-driver approaching the junction on either line may get a good view of trains on the other line; the lines also should be level, or on as good gradients as possible, and it is, of course, necessary that the two lines should be on the same gradient until one line has completely diverged from the other.

In ordinary cases of two lines of rails joining other two lines of rails as shown in fig. 8, it is obvious that one line crosses the other line on the level at the point X, and

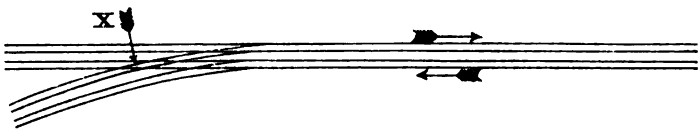


FIG. 8. Junction with all the lines on the same level.

this constitutes one of the great dangers of railway junctions. In many cases of late years this level crossing at X has been avoided by passing one line over or under the other, as shown by the fig. 9. This is a greatly superior

FIG. 9. Junction with the crossing line carried under.

arrangement, not only on the score of safety, but also because it saves much delay to the traffic, for it is obvious that while a train on one line is crossing another line on the level, traffic on that other must be entirely stopped. Such a stoppage on busy railways seriously detracts from the earning power of the railway, and produces irregularity in the running of the trains.

Junctions should be made, if possible, where there are no high embankments or deep cuttings, as it frequently happens that after the line is opened additional sidings or other accommodation may be required at the junctions, and these cannot be provided on high embankments or in deep cuttings except at great expense. Further, it is to be remembered that at best junctions are dangerous places compared with other parts of the line, and that it is on that account desirable that they should be on ground which would not aggravate the disaster of a train leaving the line.

The curves for subsidiary lines at junctions should of course be as easy as possible, but they may be sharper than at other parts of the line, because the divergence which takes place at the switches or points is of itself, as will be seen hereafter, so abrupt that the speed ought to be slackened where the switches are used to effect divergence from the main line. Therefore the curve, which continues the act of divergence, may be sharper than on ordinary parts of the line where the speed is not limited by such considerations. When the switches are in the position to allow the train to continue to travel on the main line on which it was previously running, there is no necessity for a diminution of speed of the train, provided the switches are properly adjusted and are held firm in their true position. A radius of from 20 to 25 chains is a good radius for ordinary country junctions, but there are many examples of junction curves of from 10 to 15 chains. On Metropolitan lines still sharper curves are used, as, for instance, the curves above mentioned on page 22.

All the subjects which have been referred to are matters which have to be duly weighed in settling the general line and levels of the railway: and we may now

pass on to the details of the construction of a railway. I propose in the next lecture to consider some of those particular matters which call for attention in designing and executing railway structures, but I shall not enter into the statical and mechanical principles of construction which affect the stability of all structures without having any special application to railway-making.

LECTURE II.

WORKING PLANS AND SECTIONS—DRAINAGE—TUNNELS—VIADUCTS—BRIDGES—ALTERATIONS OF ROADS—GAUGE OF RAILWAYS—BATTLE OF THE GAUGES—BREAK OF GAUGE—GAUGE OF RAILS AND WHEELS—MATERIALS FOR BALLAST.

In my last lecture I endeavoured to bring before you the general considerations affecting the earliest stages in the construction of a railway. Of these the first was the consideration whether, in any particular case, a railway should be constructed at all—and a comparison was made between road, railway, and water carriage. Next came the consideration of the class of line required and of the ruling gradients that should be aimed at, together with the matters affecting the choice of gradient in reference to various kinds of traffic. The question of the course to be adopted for the line under different conditions of ruling gradients and curves was then discussed, and I pointed out the way in which, in certain cases, the adoption of sharper curves diminished the cost of the works. Then followed a short sketch of the course taken, first in examining a country to see where ridges and valleys had better be crossed, and next in taking trial sections to determine with certainty these and other points; and, in conclusion, I referred to the various matters (such as balancing earthworks, substituting tunnels and viaducts for earthworks, providing for floods, and forming junctions with other

lines), which have to be considered, before the general line and levels of a railway can be settled, and laid down on the preliminary survey and section. The next step is to set out the line on the ground, and to prepare the working plan and section, by the guidance of which the works will be carried out.

The line is set out on the ground with great accuracy, and usually two pegs are driven into the ground at every chain. One peg is driven so that its top is level with the ground. On this peg, when the working section is being prepared, the levelling staff is held. The other peg at each chain is driven alongside the first-named peg, and is numbered in regular sequence from the beginning of the railway. This peg is left sticking out of the ground to indicate the position of the first-named peg on which the levels have been taken. Special pegs are driven at the beginning and end of each curve.

When each part of the line is set out, the preparation of the working plan is proceeded with. The position of the line as set out is laid down; every peg being shown and numbered on the plan, and the ground on each side of the centre line is accurately surveyed and plotted. The working plan is made to the same horizontal scale as the working section, and generally the width of the plan extends in country districts from five to ten chains on each side of the centre line of the railway, within which limits everything that appears on the ground is shown with the greatest accuracy. The horizontal scale usually adopted is from 2 to 4 chains to an inch; the larger scale gives great advantages in enabling the position of the new works to be shown without difficulty. The working section, which is taken along the centre line of the railway (readings being taken at every peg which is numbered and shown on the section as on

the plan), must be made with great care, as it forms the basis for the calculation of all the earthwork. The vertical scale is always much larger than the horizontal scale, and for a good working section is often 20 ft. to an inch. A working section (Fig. 10) for a railway has usually stated on it in tiers of figures at every chain :—

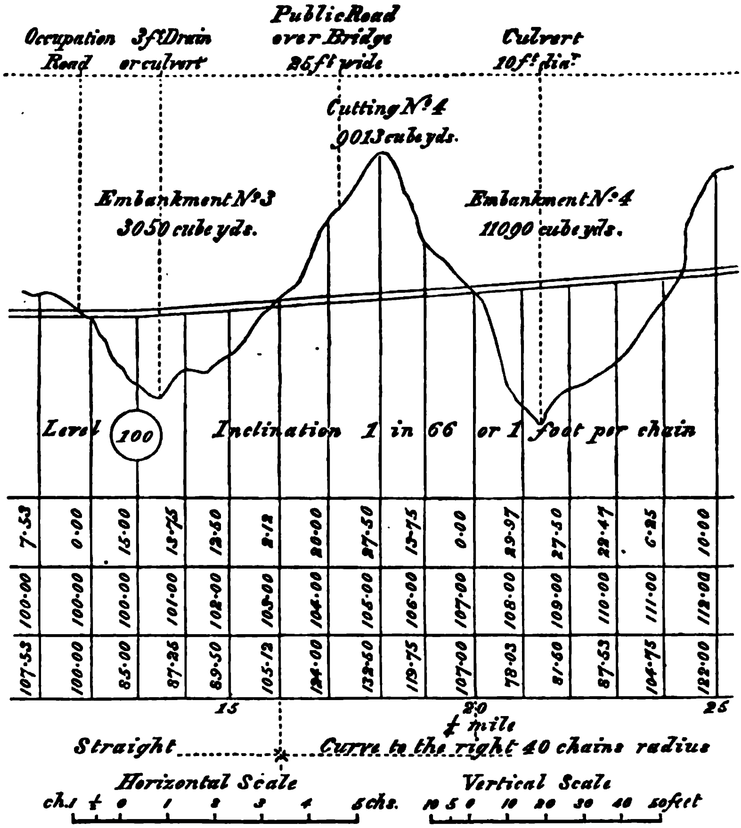


FIG. 10. Working Section.

(1) The horizontal measurements from the beginning of the railway. These are given by the numbering of the pegs as above explained, and very often by a mileage scale also.

(2) The height of the surface of the ground above a datum line.

(3) The height of 'formation level' above the same datum.[1]

(4) The difference between the second and third tiers of dimensions.

The fourth tier of figures consequently represents the actual height of each embankment or the depth of each cutting at every chain along the line of railway. Descriptions of the span of all bridges, the size of all culverts or drains, or other works, are generally given on the working section at the spot where the various works are to be built.

Cross sections will be required, and their number and extent will depend on the nature of the ground. If the ground be level, or nearly level, transversely to the line of railway, cross sections need not be taken very frequently; but if the ground be side-lying, numerous cross sections are requisite, and they should be extended for a considerable distance on each side of the centre line, in order not only to show the extent of the earthwork required for the proposed cuttings or embankments, but also to enable us to form a judgment of the effect of placing an embankment, or of making a cutting at the place in question, so that, if any deviation is desirable, the result of such a deviation may be correctly estimated.

I will now pass to the works of construction, but, as I have already said, I shall not enter into these matters further than to direct your attention to some of the special matters which affect the works of railways as distinguished from works in general.

With regard to the earthworks of railways, too much attention can scarcely be given to the drainage

[1] For the definition of the term 'formation level' see page 43.

of the slopes of cuttings or embankments, and most of the serious slips of earthworks, which, unfortunately, are not uncommon in the experience of all railway engineers, are due to neglect of this precaution in soils which call for its employment. In all cases the toe of the slope ought to be efficiently drained to prevent any accumulation of water there, and the consequent gradual softening or disintegration of the foundation of the face of the slope. It is frequently desirable to provide good catch-water drains along the tops of cuttings, and this is particularly the case on the upper side of a cutting in side-lying ground. The water from such catch-water drains is either discharged at each end of the cutting, or else (if the cutting be a long one) is turned down the side of the cutting here and there in channels well pitched with brick or stone. In many cases the surfaces of the slopes have to be drained, by making in the face of them trenches filled with porous materials, such as chalk or loose stones, which form channels along which the water collected on the surface of the slope can run to the drain at the toe of the slope. It is sometimes wise, where the ground seems treacherous, to carry deep cross trenches filled with porous material into the body of the slope at right angles to the direction of the cutting. In certain exceptional cases where the soil is specially friable, or where a run of water would disintegrate the surface, the slopes are covered with a water-tight material such as stone pitching set in mortar.

This use of pitching as a surface protection is not to be confounded with the employment of heavy pitching, which is occasionally useful for the purpose of weighting the slopes of earthwork, and thus keeping the earth from slipping.

The earth for embankments is, as has been said, usually

provided from the adjacent cuttings; and consequently an engineer cannot select the earth best fitted for the purpose of embankments, but must take what comes and use it as best he may. All the clays are as a rule to be treated with caution in forming embankments at all seasons, and some descriptions of clay cannot be used for embankments in settled wet weather. They become at such times almost liquid mud, and cannot be made to stand at any reasonable slope. London clay, which in a cutting is often too hard to be dug with an ordinary shovel, is a great offender in this respect, and becomes so soft under continued exposure to wet as to be worse than useless for making an embankment. Indeed, speaking generally, embankments of earth, other than light soil gravel or broken rock, should not be made in wet weather except in cases of necessity, when extreme precautions should be taken for the effectual drainage of the deposited soil. At all times attention to the providing of efficient means for the escape of water from the newly tipped material of an embankment will be well repaid in the avoidance of slips, which are to be dreaded not only while the embankment is being made, but also after it is finished, and when it has to sustain the weight and vibration of passing trains.

The slopes of the finished earthworks should be sown with grass to protect the surface; the roots of plants like broom and gorse are also useful in binding the earth together, and may be most advantageously employed on treacherous soils.

The upper surface of the earthworks on which the ballast and the permanent way are eventually laid is called the 'formation level,' and is shown on Figs. 11 and 12. The formation level is therefore in one case the top of the embankments, and in the other case the bottom of the

cuttings. In both cases it is beneath the level of the rails (by which term is always understood the upper surface of the rails) to the extent of the depth of the ballast and permanent way.

The width of the earthworks at formation level depends on the number of lines of way, the gauge of the railway, the length of the sleepers, the slopes of the ballast, and the width of the side ditches where these are re-

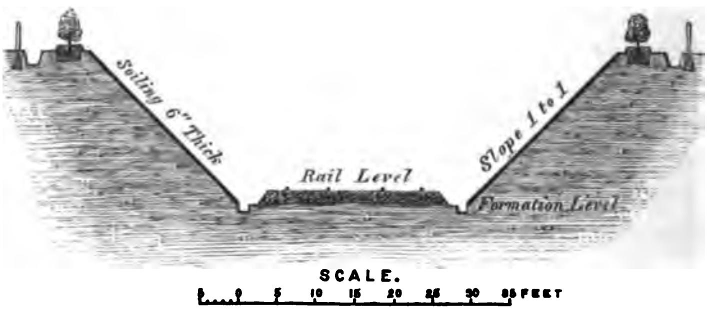


FIG. 11. Cross Section of Cutting.

quired. The formation width is generally greater in cuttings than it is on embankments, in order to afford space for side ditches, and the width varies, as the side ditches require to be more capacious in certain situations and in certain soils than in others. A cess of about ten or

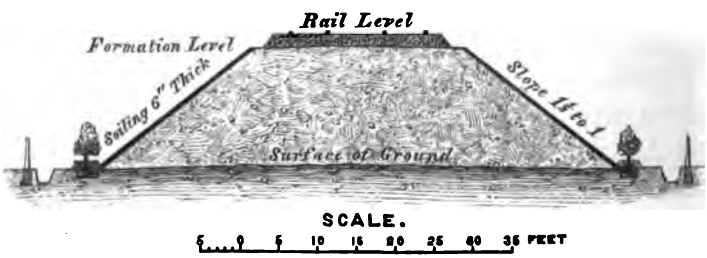


FIG. 12. Cross Section of Embankment.

twelve feet is usually provided at the top of cuttings and at the foot of embankments to afford space for fences and ditches. Figs. 11 and 12 are sections of a double

line of railway, and show the formation level and the cess ordinarily given in England. Fig. 13 is a section of a rock cutting for a single line of railway, and shows on one side the slope used for shaley rock, and on the other side the slope for limestone rock. In both cases it is supposed that a depth of about eight feet of soft soil is superimposed on the rock.

Where rock is encountered it is important, on account of the expense of rock excavation, to reduce the width of the cuttings in order to minimise the amount of rock to be excavated; and the formation width is often less in rock cuttings than elsewhere. To reduce the width of

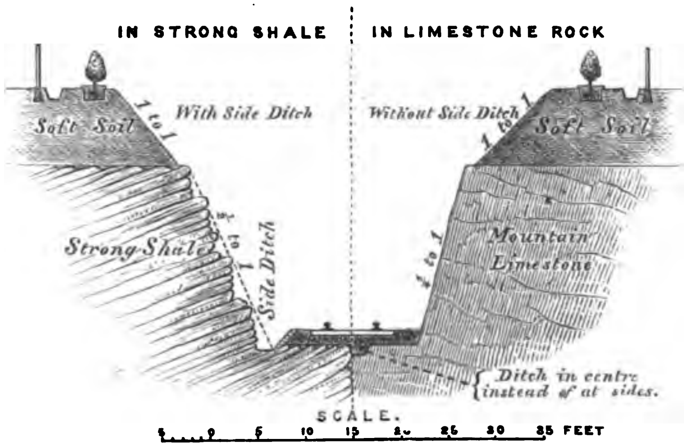


FIG. 13. Cross Section of Rock Cutting.

rock cuttings the ballast may be arranged as will be explained further on, and one side ditch may be used instead of two side ditches, the water being taken across the cutting by transverse drains at frequent intervals. The earth to be removed to make the slopes of a cutting is a quantity independent of what may be the formation width, and thus, inasmuch as the flat slopes of ordinary earthwork cuttings have much larger cubical dimensions than have the steep slopes of rock cuttings, a reduction of the for-

mation width of earthwork cuttings does not produce nearly the percentage of saving on the whole quantity of earthwork that a similar reduction of width does in rock cuttings.

In considering the relative cost of a cutting and tunnel, the width of the railway and the nature of the soil are important elements in the calculation. A tunnel for a single line costs more than half as much as a tunnel for a double line; but it is to be remembered that a tunnel saves not only the excavation of the central part of the cutting but also the excavation of the slopes, and that the amount of earth contained in the slopes of a cutting—which in a deep cutting in soft earth form the greater part of the excavation—is the same whatever the formation width may be. In rock of a soft character tunnelling is easy, as little timbering is required and blasting is unnecessary; while some of the most expensive of known tunnels are those which have been made through soft soil and London clay, for, though such soil is easily excavated, it is frequently extremely treacherous, and very strong timbering is necessary. Thus, before pronouncing definitely on the depth at which tunnelling becomes economical, we require very exact knowledge of the whole of the strata lying between the surface of the ground and the level of rails. This knowledge will enable us not only to estimate the amount of earthwork saved by tunnelling, but will afford the requisite data to enable us to estimate the probable cost of the brickwork or stonework of the tunnel itself.

The internal dimensions, cross-sections and thickness of tunnels, premising that they must be sufficiently large to accommodate the engines and rolling stock, should be designed with regard to the nature of the soil and the position which the tunnel is to occupy. Thus where the

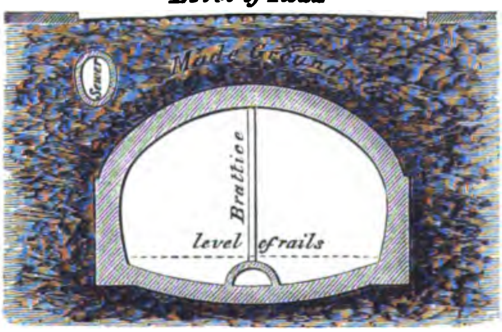
strain due to the nature of the earth and the position of the tunnel is mainly vertical, the shape is made elliptical,

Blechingley Tunnel. Narrow Gauge.

FIG. 14.

with the major axis vertical, as shown in Fig. 14; where there is little vertical strain, and where there is but little height available, as in the case of a metropolitan tunnel

Level of Road

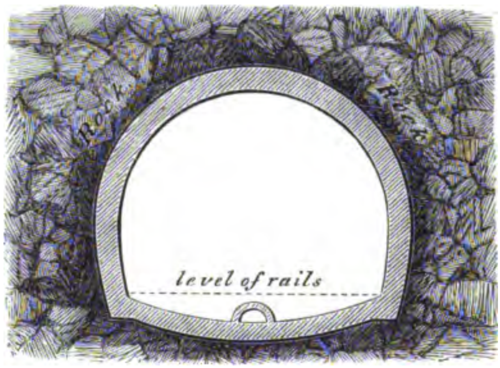


Tunnel on Metropolitan Railway Broad Gauge (With Brattice added)

FIG. 15.

beneath a street, the shape is made elliptical, with the major axis horizontal, as shown in Fig. 15. In this case,

and in the case of a tunnel through rock (Fig. 16), that shape is adopted which accommodates most conveniently the trains which have to pass through it. A nearly cylindrical form is probably best in a material such as London clay, which may almost be said to press equally in all directions. Tunnels through the side of a hill, when the pressure on one side is not perfectly balanced by the pressure on the other side, are works requiring great care and special precautions, not only to prevent the



Tunnel on Wilts & Somerset Railway Broad Gauge

Scale

5 0 5 10 15 20 feet

FIG. 16.

sides being damaged, but also to prevent the stability of the hill-side itself being disturbed.

Tunnels ought always to be made in a straight line if possible, so that an engine-driver can see through the tunnel from one end to the other when it is free from steam. Ventilation is a most troublesome matter in heavily worked tunnels. In one instance in England, viz. the Liverpool and Edge Hill Tunnel, resort has been of necessity had to artificial ventilation by means of a fan worked by a stationary engine in a large shaft near the centre of the tunnel. There is no doubt that in

tunnels of moderate length ventilation may be assisted by dividing a tunnel into two equal parts by a longitudinal vertical diaphragm or brattice, so as to keep the air always moving in one direction when it has been set in motion by the passage of trains or by any other means. When trains travel in opposite directions in an undivided tunnel the currents of air become mixed, and the steam and foul vapours are driven backwards and forwards instead of flowing in one direction. In short but heavily worked tunnels, such as those on the Metropolitan Railway, a brattice (as shown in Fig. 15) would be of utility, as in such cases the current of air induced by the passage of a train is powerful enough to move the air throughout the short length of the tunnel. Unfortunately, in most cases tunnels have been built without foreseeing the enormous amount of traffic which in course of time it has been found necessary to pass through them, and their width is usually not sufficient to allow of a brattice being now erected. A brattice in a tunnel requires that between the pairs of rails, instead of the usual space of 6 feet, a space of from 8 to 9 feet should be allowed, and thus a tunnel with a brattice should be from 2 to 3 feet wider than an ordinary tunnel.

With respect to viaducts, one chief matter calling for attention is, that usually a railway viaduct has to cross over a stream in the bottom of a valley. Great attention should consequently be given to the foundations, not only on account of the high stress on the base due to the height of the structure, but also because the centre piers have often to encounter the danger of the scour due to a water-course, while the side piers are usually founded on side-lying ground. A batter is given to the piers of a viaduct in both directions, so as to spread the

weight over an area proportionately larger as the height of the piers increases. Thus not only the foundation, but also the horizontal section of the pier at every portion of its height should be duly proportioned to the superincumbent weight. An example of this gradual spreading of the load on the piers is shown on the next page in Fig. 17, which is a sketch of one of the class of viaducts on the Cornwall Railway, having masonry piers and a timber superstructure.

Examples will occur to you of viaducts with brick, stone, timber, and iron piers, and with superstructures of the same materials. It is to be remembered that in all such superstructures, when employed to carry a railway, an engineer must provide not merely against a distributed moving load, but against the greatly concentrated loads carried on the engine wheels. Viaducts should, if possible, be straight on plan, and not curved; but there are many examples of curved viaducts that have been introduced to suit local and special circumstances.

In towns viaducts possess the great advantage of allowing unlimited freedom of crossing to and fro beneath the railway, and the arches of viaducts in large towns can be let at considerable rents. In a case which came under my notice in London the rents received from the tenants of some railway arches paid more than 5 per cent. on the cost of the construction of the viaduct. I do not mean to infer that such a financial result can be attained except in a central position in a large town, but the fact that it has been realised in such localities shows the importance of designing viaducts in cities in such a way that the spaces beneath them may be easily adapted to commercial or habitable purposes.

The same remark applies to bridges carrying railways over streets in towns. In country roads we reduce the spans of the bridges to the minimum allowed by

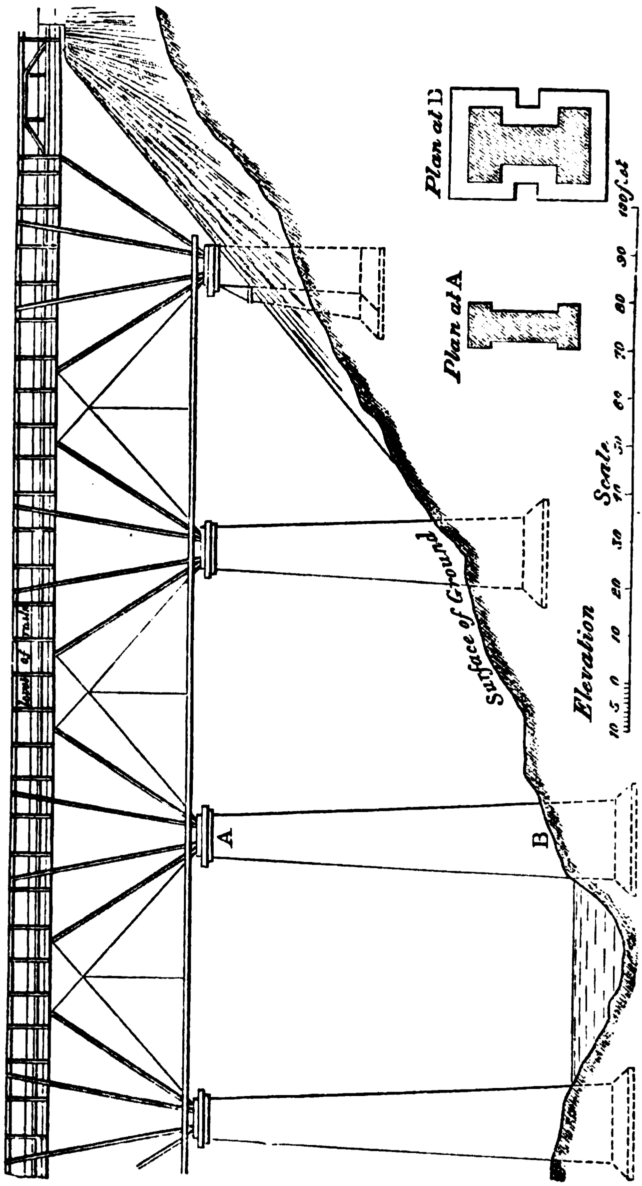


Fig. 17. Viaduct with stone piers and timber superstructure.

the Acts of Parliament, and this is often done also in towns; and a town railway bridge is usually made of a span barely as wide as the street across which it is placed. But the more prudent course in many cases of girder bridges over streets would be to set back the abutments on which the ends of the girders rest, so as to leave room between the abutment and the frontage line of the street for small shops or other tenements. The girders in such cases might be supported by columns at the frontage line so as not to increase the length of the central span. In large towns the value of land having a frontage to a good thoroughfare is so great that the extra cost of the works would be well repaid by the extra rent so obtainable.

Bridges over a railway have of course to be wide enough and high enough to accommodate the railway company's rolling stock. The ordinary minimum headway is from 13 feet 6 inches to 14 feet, and occasionally the arch is made of such a height and shape as barely to accommodate the funnel of the locomotive, and to allow the broadest vehicle on the railway to pass beneath it (see fig. 18). The width for a double line of way of narrow gauge under a bridge varies on different railways, and should be proportioned to the rolling stock in use. An ordinary minimum width is 24 feet, which is arrived at as follows:—

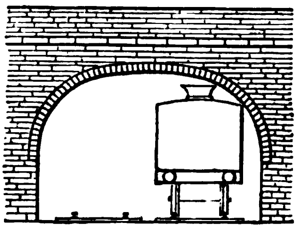


FIG. 18. Minimum Structure.

	ft.	in.
Two lines of way (4 ft. 8½ in. each between rails) .	9	5
Width of rails (4 times 2¾ in.)	0	11
Space between lines of way	6	0
Space between rails and side walls of bridge (twice 3 ft. 10 in.)	7	8
Total .	24	0

For a single line of narrow gauge railway the minimum width beneath bridges may be 12 feet 10 inches, or 13 feet, arrived at thus:—

	ft.	in.
Width of one line of way between rails . . .	4	$8\frac{1}{2}$
Width of two rails (twice $2\frac{3}{4}$ in.)		$5\frac{1}{2}$
Space between rails and side walls of bridge (twice 3 ft. 10 in.)	7	8
Total .	12	10

The boundary lines arrived at from the minimum width and minimum headway of bridges, and from the height and distance from the rails of the platforms or other work standing alongside or between the rails, are called the lines of minimum structure, and have to be constantly borne in mind when designing any structures over or alongside a railway.

The space between the rails and the side walls has been much increased of late years, owing to the great overhang now given to railway carriages; and in tunnels, such as those on the Metropolitan Railways, the space has now been increased to 4 feet 6 inches or 5 feet. In these tunnels recesses also are made, into which the platelayers can retire while a train is passing, and in which their tools can be placed. The Board of Trade recommends that a clear space of 2 feet 8 inches should be given between the side of the widest vehicle and the side walls of all bridges or any standing work alongside a railway, but this width cannot be given on many of our older lines.

With regard to bridges under the railway, the requirements in England by law are that in the absence of special circumstances—

a. A turnpike road bridge must be at least 35 feet wide in the clear between the abutments, and must have

a clear headway of 16 feet in height for a minimum width of 12 feet (see fig. 19).

b. A public carriage road bridge must be 25 feet wide in the clear, with a headway of 15 feet for a minimum width of 10 feet (see fig. 20).

c. A private or occupation road bridge must be 12 feet wide in the clear, with a headway of 14 feet for a minimum width of 9 feet (see fig. 21).

The figs. 19, 20, and 21 explain what is intended

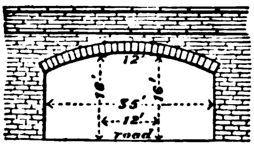


Fig. 19. Turnpike road bridge.

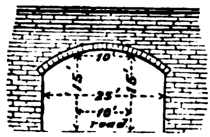


Fig. 20. Public carriage road bridge.

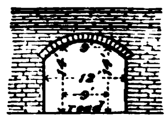


Fig. 21. Occupation road bridge.

by the regulations as to headway of bridges under railways. The dimensions for width must in skew bridges be measured on the square or at right angles to the direction of the road.

The above widths of public road bridges need not be given if the roads to be crossed are narrower than those widths within 50 yards of the point of crossing, but no public road bridge may be made narrower than 20 feet.

Bridges carried over the railway must have the same width in the clear, measured on the square, between the parapets, as bridges under the railway.

In carrying a road over or under a railway it often happens that the road has to be raised or depressed, and the gradient of the road has to be altered. The rules in England as settled by law are that the gradient of such alteration need not be better than an existing gradient on the same road within 250 yards of the point of crossing; but where the existing gradients within 250 yards of the point of crossing are better than those mentioned

below, the worst gradients permitted to be used are as follows :—

Turnpike roads, 1 in 30.
Public carriage roads, 1 in 25.
Private or occupation roads, 1 in 16.

A point that has to be borne in mind in the construction of bridges is the expediency of constructing them for double or for single line. It is a common practice in this country with small railways to make the earthworks and also the bridges by which the line passes over roads for a single line; but it is generally the case that the bridges carrying roads over the railway are made for a double line, since subsequently to widen the opening in these would in most cases involve the reconstruction of the arch, which would be expensive and inconvenient to carry out while the traffic was running.

Level crossings remain to be referred to. In this country level crossings on public roads are very seldom permitted on new railways, and on old railways public road level crossings are becoming less in number, as the railway companies appreciate the necessity of substituting bridges for them. Indeed, as the employment of a gatekeeper is obligatory in the case of public roads crossed on the level, it often happens that it will pay a railway company to build a bridge in lieu of the level crossing.

Reckoning the wages of a gatekeeper at 1*l.* a week, and assuming that (as in many cases is necessary) the services of two men are required—viz. one on duty and one off duty—a public road level crossing entails a yearly expenditure by the company of 104*l.* in wages. This sum capitalised at 5 per cent., or 20 years' purchase, comes to 2,080*l.* If only one man is wanted the capitalised sum

would be 1,040*l.*, and even this latter sum is above the average cost of an ordinary public road bridge.

In foreign countries, where traffic is light, it is another matter, and there level crossings may be usefully employed. In all cases of level crossings the gates should be so arranged that when they are opened to allow of the railway being crossed by the road traffic, the gates should shut completely across the railway so as to prevent the possibility of cattle or other animals straying along the line. The road across the railway is made as nearly as possible level with the top of the rails, and guard rails or timbers are placed about 2 in. from the inside of the rails to allow of free space for the passage of the flanges of the wheels, and to maintain the level of the ballast or paving between the rails. Public road crossings should be efficiently protected by signals, to which reference will be made in a subsequent lecture. Level crossings of a railway in countries populated as thickly as England are at the best objectionable, and in many cases dangerous both to road and railway traffic; and this remark applies not only to level crossings of public roads but also to those of private roads. I recently had my attention called to a level crossing of a farm road entirely unprotected by signals, where it was no uncommon thing at certain times of the year for the crossing to be used by farm waggons or cattle a hundred times in a working day. If it be desirable to get rid of public road level crossings which are provided with a gatekeeper and signals, it stands to reason that such a private crossing as I have described should not be allowed.

Having given this cursory glance at some of the special matters requiring consideration in railway construction, as distinguished from general construction, I shall now proceed with a more detailed description of

the railway proper; for, as has been justly said by a distinguished engineer, although lofty embankments and deep cuttings, bridges, viaducts, and tunnels are all necessary for forming the level surface upon which the rails are to be laid, yet they are but the means for obtaining that end; and the ultimate object for which these great works are constructed, and for which the enormous expenses consequent upon them are incurred, consists merely of four level parallel lines not much above two inches wide of a hard and smooth surface.

Above the formation level is placed the ballast, and on the ballast the sleepers, chairs, fastenings, rails, fishplates, points, crossings, and all the materials which form the road on which the railway vehicles run and which collectively are known by the name of permanent way.

The expression 'permanent way' was originally and is still employed to distinguish the materials of the finished railway from the materials of the temporary tramroads used by contractors during the construction of the line, for making the embankments or cuttings, and for carrying materials for the railway from one place to another.

Figs. 22 and 23 are cross sections of a single line of railway, and show the different parts of the permanent way, to each of which parts reference in detail will be made further on. In fig. 22 the line is shown with double-headed rails in chairs placed on cross sleepers, and in fig. 23 the line is shown with flat-bottomed or, as they are sometimes called, 'Vignoles' rails resting on cross sleepers, but without chairs.

The term 'line of way' signifies the line or track formed of two rails on which a railway train runs, and the gauge of the line is the clear distance between these two rails.

The space between adjacent lines of way is generally in this country at least 6 ft. in the clear between the outside edges of the rails. The gauge being also of a fixed width, the central part of a railway, or the distance between the outside rails, has an uniform width, while the space at the sides is, as has been explained above, dependent on variable conditions, such as the length of the cross sleepers used, and the necessity in places for side ditches.

The standard gauge of railway in Great Britain is 4 ft. 8½ in. for narrow gauge lines, and 7 ft. for the broad

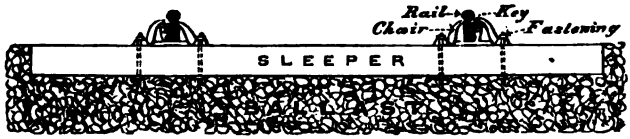


FIG. 22. Cross section of a railway with double-headed rails in chairs.

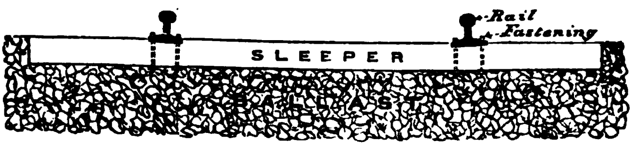


FIG. 23. Cross section of a railway with flat-bottomed rails.

gauge lines, which latter are entirely comprised in the systems of the Great Western Railway Company and the lines affiliated or amalgamated with it, viz. the Bristol and Exeter, the South Devon, and Cornwall Railways.

The Great Western Railway, which was originally constructed and worked entirely on the broad gauge of 7 ft., has now but little exclusively broad gauge remaining. The greater part of its system is composed of narrow gauge, or of mixed gauge, viz. railway laid with three rails so that either narrow or broad gauge rolling

stock may run on it; the only portion of the exclusively broad gauge lines remaining being some parts of the system west of Bristol. As soon as those parts are laid with the narrow or mixed gauge, which alteration will probably be made before long, England and Scotland will possess the great advantage of an unbroken gauge on all the main lines of railway.

There are a few mineral and private lines on a gauge narrower than 4 ft. 8½ in., but these are exceptional and isolated cases, where the narrowness of the gauge has been adopted for local and special purposes, and these need not be referred to in detail.

The standard gauge of Ireland was settled by Act of Parliament in 1846 at 5 ft. 3 in. The standard gauge of British India until lately was exclusively 5 ft. 6 in., but now there are two gauges—viz. the 5 ft. 6 in. gauge on the trunk lines, and a second gauge of 3 ft. 3·3708 in., or 1 French mètre, for subsidiary lines.

The gauge over the greater part of Europe is the same as our standard narrow gauge—viz. 4 ft. 8½ in., but the Spanish gauge is 5 ft. 6 in., and the Russian gauge is 5 ft. In the United States the gauges vary from 3 ft. to 8 ft., and there is no standard gauge.

Some of the railways in the United States which are continuous differ slightly in gauge to the extent of one or two inches, and rolling stock is interchanged between those lines, though with the inconvenience of the wheels running tight or loose as the case may be. Attempts have been made in cases where there are greater differences of gauge to construct rolling stock with wheels which should be capable of sliding on their axles, so as to admit of adjustment to different gauges, but the experiment has not been very successful.

Below are enumerated the gauges of some of the

principal countries of the world, including those already referred to:—

	ft.	in.		ft.	in.	ft.	in.
Great Britain	4	8½	and	7	0		
Ireland	5	3					
British India	1 mètre		and	5	6		
Ceylon	5	6					
Canada	4	8½	and	5	6		
Nova Scotia	4	8½	and	5	6		
Australia—							
New South Wales	4	8½					
Victoria & South Australia	5	3					
Queensland	3	6					
Tasmania	3	6					
New Zealand	5	3					
Cape Colonies	3	6					
France	4	8½					
North Germany	4	8½					
Russia	5	0					
Holland	4	8½					
Belgium	4	8½					
Austria	4	8½					
Hungary	4	8½					
Turkey	4	8½					
Switzerland	4	8½					
Italy	4	8½					
Norway	3	6	and	4	8½		
Sweden	4	8½					
Denmark	4	8½					
Spain	5	6					
Portugal	5	6					
Egypt	3	6	and	4	8½		
United States	3	0		4	8½	4	9
	4	10		5	0	5	6
	6	0		8	0		
Brazil	1 mètre			3	6	4	0
	4	3		4	8½	5	3
	5	6					
Argentine Republic	1 mètre		and	5	6		
Uruguay Republic	4	8½					
Chili	5	6					
Peru	4	8½					
Japan	3	6					

The battle of the gauges was one of the earliest, and it has also been one of the latest, of the railway contests. It was fought in the early days of English railways, and has again been vehemently discussed of late years in connection with the system of Indian railways. The contest in England ended in the adoption of two standard gauges, viz. the broad gauge of 7 feet and the narrow gauge of 4 feet 8½ inches, and, as we have just seen, the result here has been that at the expense of laying a third rail in some places and of sacrificing the broad gauge system and its rolling stock in others, we now have or shortly shall have retraced our steps and shall possess a gauge unbroken throughout England and Scotland. In India the government originally adopted a gauge of 5 ft. 6 in., impelled probably to that conclusion by considerations of the advantages of a gauge of that width in affording space between the wheels for the convenient arrangement of the machinery of the locomotives. They have now, as my hearers probably know, adopted the much narrower gauge of a mètre for their new lines, with the idea that much first cost will be saved in the construction of the line by so doing. I do not think that any one can contend for a saving of working expenses by reason of adopting the narrower gauge. Indeed, the experience in England has been, as one might expect, that the working expenses of the broad gauge system itself, neglecting the expenses entailed by the break of gauge where traffic is interchanged, are less than those of the narrow gauge lines. The policy of the change, which still remains to be proved, has always been based on economy in the construction of the line, and not of working it. I cannot help thinking that the mètre gauge has disadvantages in the matter of the construction of the locomotive which will be found serious as time goes on, and that the nar-

rowness of the gauge has been credited with too much saving of first cost. In drawing comparisons between the two gauges it has often been the custom to compare the mètre gauge line with a railway of the broader gauge, made as a main line with heavy permanent way, with structures adapted to the greatest loads carried on the broad gauge engine wheels, completely ballasted and finished like a main line, such as the East Indian Railway. If, however, the mètre gauge line were compared with a light railway of the wider gauge, on which the loads to be carried on each pair of wheels were limited to the same amount as those carried on the mètre gauge, I think the saving would not be very great, and probably not commensurate with the disadvantages of diversity of gauge.

It is to be remembered on this subject that the strength of the permanent way and of the bridges ought to be measured by the loads concentrated on the wheels which are most heavily loaded, and that these are the wheels of the locomotives. There is no difficulty in dividing the weight of any locomotive over a large number of small wheels such as those used on the mètre gauge lines, and thus the cost of the rails and fastenings for a light railway of a broad gauge need not be more than for a narrow gauge. It is also to be remembered that the width from out to out of mètre gauge rolling stock is not very much less than the width of the rolling stock of the wide gauge, the overhang in the former case being considerably more than in the latter, and thus in the two cases the width of structures over the railway, such as bridges and tunnels, will not be materially different; and, lastly, that the width of the piers of bridges and viaducts is prescribed by the question of their stability as structures, and that they can rarely be

reduced lower than the width required for a single line of railway of the ordinary gauge.

I do not wish to be understood as saying that there is no saving in first cost by adopting a gauge as narrow as a mètre, and I particularly wish not to be thought to be alluding to a comparison between a broad and a narrow gauge line in mountainous countries, but I think the question as to its true economy in flat or tolerably flat countries is one for very anxious and dispassionate consideration; for while the inconvenience of a break of gauge is at all times serious, and may at some crises of a nation's history be disastrous, it may turn out on a true investigation of all the advantages and disadvantages that a light line of the old gauge may not be seriously more costly in the long-run, even financially, than such lines as those on the mètre gauge. It may probably be the lot of some of those whom I am addressing to come into contact hereafter with this important subject, either in India or elsewhere, and I would merely desire to bespeak close attention to all the questions involved, including not only first cost, which is, no doubt, of great weight, but also the cost of working the locomotive department, and the cost of transhipment where the break of gauge occurs. Unless each gauge forms a complete network throughout the country, the task of reinforcing the rolling stock of any isolated district, in case of emergency, will be very great, as, though there may elsewhere be an ample quantity of spare engines and vehicles, they cannot travel on their own wheels to the place where they are wanted.

The military questions involved by a break of gauge remain to be dealt with. All that a civilian can say on that point is that from a knowledge of what is involved by a break of gauge in times of peace, when one has plenty of time at one's disposal, it would seem that the incon-

venience of a break of gauge in transporting, in time of war, artillery, ammunition of war, horses, military stores, and food, and in concentrating the special railway rolling stock where required, under every kind of high pressure, must of necessity be immense, and not measurable by any figures or calculations.

There is, however, another argument put forward for the mètre gauge as compared with the broad gauge—put forward not so much directly as by implication. This argument is as follows: True, we can make a light broad gauge line nearly as cheaply as a metre gauge line, if, as we very well can do, we make our loads on each wheel light, and run at moderate speed; but we cannot trust ourselves to make such a line, for we know if we begin to make a light broad railway that before we have finished, or perhaps even after we have finished, we shall not be able to resist the temptation to strengthen our bridges, and to put heavier rails to make the line as good, and to carry as heavy loads, as the trunk line. So that in fact the only way to insure having a cheap line is to make it in some new pattern which it will be impossible to alter into an expensive line. This appears to me to be a puerile treatment of an important matter, and I can only express my conviction that those who are entrusted with the supervision of this subject and with the execution of light railways, broad or narrow, do not require such elaborate measures to keep their expenditure within bounds.

I am anxious not to be thought to advocate or approve of so wide a gauge as that originally adopted, viz. 5 ft. 6 in., for British India. Probably if the choice had now to be made it would fall in with the gauge of England, 4 ft. 8½ in., which is no doubt for all practical purposes wide enough. What I wanted rather to direct attention to is the break of gauge which has been deliberately adopted,

and to point out, on the one hand, the many weighty reasons which exist against the break (particularly in a country such as India), and, on the other hand, the modes which exist of getting a cheap line of a light construction and of the standard gauge.

The term 'gauge of a railway' is generally understood to mean the shortest distance between the inside edges of the upper surfaces of the rails, but the word 'gauge' also applies to the instrument by which that distance is measured. Each gang of platelayers has an iron standard measure or gauge of the proper distance between the rails, and it is the business of the foreman of platelayers to see that all parts of the line under his supervision are laid and kept accurately to the standard. The measuring instrument or 'gauge' consists of an iron rod with a prong a short distance from each end, and is shown in fig. 24.

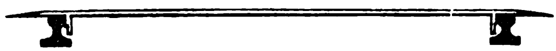


FIG. 24. Platelayer's gauge.

The ends of the rod are flattened out, so that they will lie on the upper surface of the rails, and the distance between the outside edges of the upper part of the prongs is the gauge of the railway.

The wheels of railway vehicles are, as you know, made with flanges, in order to prevent them from running off the rails, and they are fixed firmly on the axle so that the wheels revolve together. The wheels are almost invariably attached rigidly to the frame of the carriage, and cannot adjust themselves radially to the curved parts of the line.

On plan a railway carriage going round a curve is seen to be a rigid parallelogram, travelling between two concentric curved lines, and it is evident that if all the flanges were absolutely tight against the rails, and no play

were allowed, carriages with more than two wheels could not be placed between the rails, unless the axles were radial to the curve.

To allow then of the vehicles running round curves, the distance between the outside of the flanges of a pair of

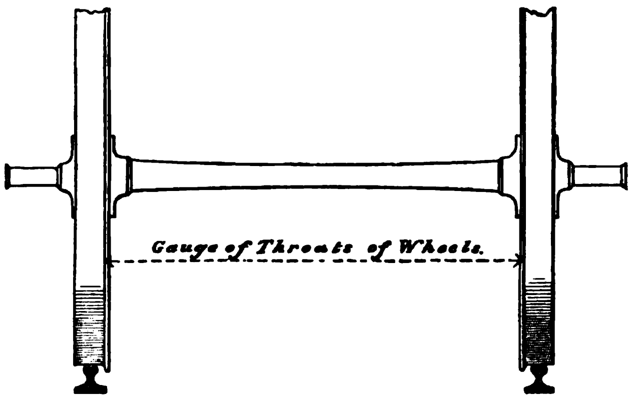


FIG. 25. Clearance between rails and wheels.

wheels (shown by the dotted line in Fig. 25), or, as it is technically termed, the 'gauge of the throats of the wheels,' is made from $\frac{3}{4}$ to 1 in. narrower than the gauge of the railway. The difference of the respective gauges of the rails and of the wheels is called the clearance, and the wheels move sideways on the rails, to the extent of the amount of clearance.

At switches and crossings the gauge of a railway is ordinarily made about $\frac{1}{4}$ to $\frac{3}{8}$ of an inch narrower than at other parts of the line, in order to lessen the sideways motion or play of the wheels of vehicles, and so to prevent their striking against the tongues of the switches or the points of crossings. A platelayer's gauge has generally the measure or gauge for switches or crossings shown on it by a slight cranking of the prongs halfway of their height (see Fig. 24), and thus at switches or crossings

the gauge will only drop in between the rails as far as the cranking in the prong will permit, but in other parts of the line it will drop in as far as the top of the prong.

In laying or repairing a line of railway the gauge is placed so that the ends rest on the tops of the rails; the rails are pushed inwards till they are in contact with the two prongs, and the rails or chairs are then fixed in their position.

The general requirements of permanent way are that all its parts must be strong enough to bear without damage the heaviest loads which are to come on the line. The severest strains to which the line can be subjected are, as I have already remarked, determined by the heaviest loads carried on any particular pair of wheels. In the case of lines worked by locomotives the heaviest loads are on the driving wheels of the engine, as, unfortunately for the maintenance and renewal of the permanent way, the only way by which up to this time the power of the locomotive has been applied to the traction of trains is through the adhesion due to the insistent weight of the driving wheels on the rails. The weight on the driving wheels of large engines such as drag the Great Northern express trains is as much as 15 or 16 tons on a pair of wheels, or 8 tons on each wheel, when the engine is travelling steadily; and this may be much increased when the engine is lurching.

This great weight is most damaging to the permanent way; and efforts are made on most railways to get rid of concentration of weight, without giving up any of the tractive force due to the weight, by distributing the weight required for adhesion over two, three, or four pairs of driving wheels coupled together. The system of coupling engine wheels has, however, many disadvantages, and it is a moot point whether it is less damaging to the per-

manent way than heavier concentrated loads carried on a pair of uncoupled wheels. A coupled engine does not travel so easily as an engine with one pair of driving wheels, and the slightest inequality in the diameter of wheels coupled together produces a detrimental action on both the wheels and the rails. Small inequalities of the road produce much more friction with coupled wheels than with single-wheeled engines, and thus what is gained by a reduction of concentrated weight is more or less neutralised by accompanying disadvantages.

It is much to be wished that some means could be found of applying the tractive force of the locomotive through all or through most of the wheels of the vehicles forming a train. If this could be satisfactorily accomplished, instead of the permanent way being exposed to strains from driving wheels supporting from 10 to 16 tons on a pair of wheels, it would have to bear little more than the strains due to the weights of the heaviest loaded trucks or carriages, which rarely have more than from 3 to 8 tons on a pair of wheels. It would be difficult to estimate the saving which such a revolution might effect in railway working expenses.

In order that permanent way may be strong enough to bear without damage the heaviest loads which can come upon it, the following conditions should be complied with:—

1. The area of the sleepers bearing on the ballast should be large enough to avoid risk of their subsidence under the loads travelling over the line.

2. The bearing area of the chairs on the sleepers, or, if there are no chairs, the bearing area of the rails, should be large enough to avoid crushing of the wood and the consequent sinking of the chair or rail into the wood.

3. If chairs be used, the bearing area of the rail on

the chairs should be large enough—or some other means should be adopted—to avoid damage to the under-side of the rail.

4. The rail should be strong enough either in itself, or when assisted by longitudinal sleepers, to avoid deflection vertically or sideways beyond the proper limits of its elasticity.

5. The two rails forming a line of way should be so securely fastened that they cannot spread apart sideways, and play or slackness in the fastenings should as far as possible be avoided.

6. The rails should be connected endways, so that the joints between them may be as nearly as possible of uniform strength with the rest of the line.

7. The material of which the rail is made should be such as will resist not only the strains due to the rail acting as a girder under a passing load, and the intense local pressure of the weight on a very small surface, but also the abrasion caused by the grinding or sliding action of the wheels on the surface of the rails.

8. The permanent way, considered as a whole, should be sufficiently elastic to 'give' a little under the passing loads, but in such a way that the several parts cannot work loose.

9. The vertical distance between the upper surface of the rails and the supporting surface of the ballast should be as small as possible, in order that the leverage tending to disturb the permanent way on its bed on the ballast may be proportionately reduced.

These being the general principles to be aimed at in the construction of efficient permanent way, the several parts of permanent way in ordinary use have next to be considered.

We will commence with the ballast, which is the

foundation of the permanent way, and which is very commonly treated as part of the permanent way itself.

The formation level of a railway is generally about 2 ft. below the upper surface of the rails, and thus if the top of the ballast is (as is usually the case) about level with the under surface of the rails there would be a thickness of ballast of about 1 ft. 7 in. above formation level. A greater thickness of ballast is occasionally used in cuttings, for the purpose of providing more efficient drainage below the sleepers, as water is more apt to accumulate in such positions than on the top of an embankment.

In hot dry weather the ballast is often heaped up against the rails on the side on which the wooden keys which secure the rails in the chairs are placed, in order that the ballast may partially cover the keys, and so modify the action of the sun in drying them, and causing them to shrink and become loose in the chairs. The ballast in such cases also acts usefully in preventing any shrunken keys from shaking out of the chairs, which cannot take place so long as the ballast restrains the keys from moving endways.

Too much care can scarcely be given to the efficient drainage of the ballast. Any accumulation of water between the sleepers and the ballast on which they rest, or in the ballast generally, acts most prejudicially to the security and durability of the road, and may affect the stability of the earthworks. It is important that the ballast supporting the sleepers should be a hard material which can be readily packed under and round them, but it is equally important that it should afford an easy passage through which the water can run away from below the sleepers. If water is allowed to lodge underneath the sleepers, every time a train passes the sleepers

are pressed down, and the water is squirted up at the sides and ends of the sleepers. In such cases some kinds of ballast under continued attrition gradually become mud, and the sleepers subside more and more as the process goes on. This action may at times be seen on railways, where either bad ballast has been employed or where the side drains are inefficient.

Ballast should be composed of a hard and unfriable material, such as gravel, broken stone, broken bricks, hard burnt clay, or slag from blast furnaces, and great care should be taken to exclude from it dirt or soluble substances. If burnt clay is used—as is sometimes the case in localities where the other materials above-mentioned are not easily to be obtained—it should be burnt as hard as possible, so that it may not be crushed or become dusty under the weight of the trains. Hard broken stone or sound broken bricks are often too expensive to be used as ballast, from the first cost of the materials themselves as well as from the cost of the labour required to break them; but occasionally these materials are available, and, if they can be used, answer admirably.

One of the best materials is slag from blast furnaces, which is now extensively used on railways in the iron districts. Slag, when broken or cast in small pieces, is extremely well suited for ballast, and is perhaps the best material to be found. It is, moreover, a great advantage to the ironmaster to find a use and a market for his slag, which until lately was worse than useless, causing him great difficulty and expense in finding places where it could be deposited.

The material, however, most generally used is gravel, which answers its purpose extremely well when it is free from loam or dirt. On coast lines shingle from the beach is often employed, and forms excellent ballast.

Care should, however, be taken that no great quantity of shells is mixed with the shingle, as they will be crushed under heavy weights, and cause the ballast to become dirty.

In many cases materials for ballast can be obtained of uniform quality, and composed of stones, at once suitable for the upper portions of the ballast, which have to be packed round and under the sleeper, and for the lower portions of the ballast, the object of which is to provide efficient drainage. Such a description of material is shown in Figs. 22 and 23 (p. 58), there being no difference in those figures between the upper and the lower ballast. When, however, stone, slag, or bricks have to be broken, or where the gravel in its natural state contains stones which are too large for the upper ballast, the coarse and fine materials are separated the one from the other, the former being put into the lower half of the depth of the ballast used, and the latter into the upper half, as shown in Fig. 26. The upper ballast would in such cases be composed of stones or fragments, each of which would not exceed 3 cubic inches in bulk, and would average about two cubic inches, while the lower ballast would be composed of stones or fragments of from 3 to 30 cubic inches.

The width of the top of the ballast beyond the ends of the cross sleepers is generally about 18 inches. Thus, the width of ballast for a single line of railway is, at the top 12 ft., for a double line 23 ft., for a treble line 34 ft., and for a quadruple line 45 ft. The slopes of the ballast at the sides are usually about 1 to 1, at which inclination good ballast stands well. Occasionally, in expensive cuttings, as has been already referred to, or where natural ballast is scarce, and where, consequently, stone or brick or slag has to be broken for ballasting the line, it is

desirable to keep the width of ballast as narrow as possible. In such cases the necessity for side slopes is avoided by roughly packing the sides with large stones placed nearly vertically, so as to resemble a dry retaining wall, as shown in Fig. 26.

The width, depth, and slopes of the ballast for a line laid with longitudinal sleepers are usually much the same as those for a line with cross sleepers; but for light

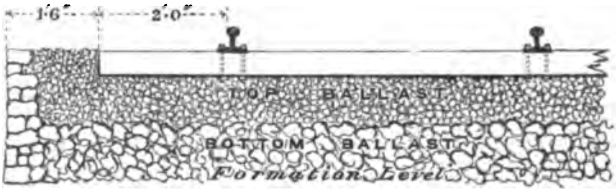


FIG. 26. Rough ballast packed at the side.

railways the ballast might be concentrated under the longitudinals, in order to diminish the amount required.

In this country railways invariably have ballast more or less good; but in some foreign countries, where ballast is not to be procured, railways are laid without any ballast. The sleepers, which in such cases are generally of iron, are usually laid in the best soil that can be found; and when the soil procurable affords little or no facility for drainage, the top of the railway is dressed to a curved surface, so as to assist the water to flow off the railway to the sides of the line. I have seen many lines laid entirely without ballast, and was surprised to find in what good order the permanent way was maintained.

LECTURE III.

DIFFERENT DESCRIPTIONS OF PERMANENT WAY—SLEEPERS—LONGITUDINAL COMPARED WITH TRANSVERSE SLEEPERS—CHAIRS—IRON SLEEPERS—DOUBLE-HEADED RAIL—'VIGNOLES RAIL'—BRIDGE RAIL—ACTION OF WHEELS ON RAILS—WHEELS ON CURVES—MANUFACTURE OF RAILS—FISH-PLATES—FASTENINGS—KEYS—SUPER-ELEVATION—CURVE OF ADJUSTMENT.

In my last lecture I brought down my description of the railway to the completion of the ballast.

The weights which rest on the small upper surface of the rails have to be distributed over a much larger surface of the ballast, which will be sufficient to bear the weight, just as we make large footings or foundations to distribute the weight of any structure over a large area. This distribution of weight is effected in rare cases by making the lower part of a specially designed rail so broad as to afford sufficient bearing area on the ballast, but ordinarily by introducing between the rail and the ballast intermediate appliances, of which sleepers and chairs are the most important.

An example of a rail made with a sufficiently broad base is the 'saddle-back,' or 'Barlow rail' (Fig. 27), which was designed to dispense with sleepers and chairs altogether. The rail is laid directly on the ballast, and the ballast is intended to completely fill the inside of the saddle-back. The bearing area on the

Fig. 27. Barlow rail.

ballast can no doubt in this way be made large enough to support the loads coming on the line, but the Barlow rail, unless its two sides be held fast, is vertically weak; while unless the ballast be kept absolutely tightly packed into the rail the wings of the rail spread elastically, and, working in and out, gradually displace the ballast beneath them. The Barlow rail has been largely used at home and abroad, and was thought at one time likely to form a very desirable and efficient description of road, composed of lasting materials with a minimum number of parts and fastenings; but experience has shown that so far at least as it has up to this time been used it leaves much to be desired, and that it is not well fitted for high speed or for heavy traffic.

Of other rails I need only mention three kinds, all of which require the addition of some kind of sleeper to distribute the weight upon the ballast. These are—

(*a*) The double-headed rail (Fig. 28), which has to

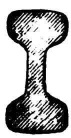


Fig. 28. Double-headed rail.

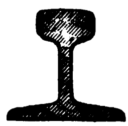


Fig. 29. Flat-bottomed rail.

Fig. 30. Bridge rail.

have chairs, as they are called, to keep it upright in place on the sleeper; (*b*) the flat-bottomed or Vignoles rail (Fig. 29), which requires no chair, but rests directly on the sleeper; and (*c*) the bridge rail (Fig. 30), introduced by the late Mr. Brunel for use with longitudinal sleepers. I will describe the special characteristics of each of the above well-known sections of rails further on, and after I have referred to some of the other parts of permanent way.

Sleepers in the present day are of wood or of

iron, and there are in general use but three kinds: 1. The wooden longitudinal sleepers (Fig. 31), which,

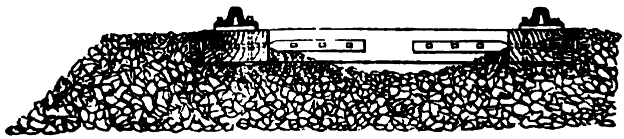


FIG. 31. Longitudinal sleeper road.

parallel to the line, extend under the whole length of each rail, thus giving continuous support to the rail throughout its length. 2. The wooden cross sleepers (Figs. 22 and 23, page 58), which, transverse to the line, support the rails at intervals, each sleeper supporting one point of each of the two rails forming one line of way. 3. The iron-pot sleepers (Fig. 32), which are placed at intervals under each rail, each pot supporting one rail at one point.

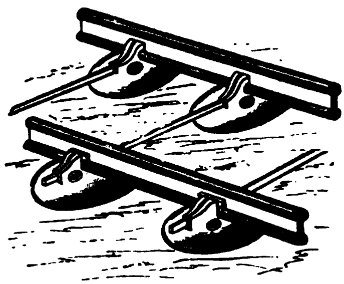


FIG. 32. Iron-pot sleepers.

Chairs, Fig. 36 (page 84), which, as I have said, are employed almost exclusively in connection with double-headed rails, are usually made of cast-iron. Where cast-iron pot sleepers are used, and double-headed rails are also used, the chair forms part of the same casting as the pot sleeper.

Thus, except in the case of the Barlow rail, we have, as essential parts of ordinary permanent way, rails and sleepers; and, where double-headed rails are used, we have also chairs.

I shall best bring before you the relative characteristics of the different forms of permanent way by describing in order the sleepers, chairs, rails, fish-plates, and fastenings; and by pointing out in each case the

mode in which each of the parts is applied in the construction of the different descriptions of permanent way to which I have alluded.

Beginning, then, with Sleepers. The materials that have been employed for sleepers are stone, wood, and iron. Stone sleepers, now very rarely seen, were much used in the early days of railways in this country, and possessed the great advantage of durability. They consisted of stone blocks measuring about 2 ft. square and 1 ft. thick, to which a cast-iron chair was attached by wooden trenails, driven into holes made in the stone. The blocks were placed about 3 ft. apart, from centre to centre, and they answered their purpose fairly well. The disadvantages attending them were, however, considerable. They were weighty and cumbrous, both to fix in the first instance and to move when the line required packing. The stone blocks also being unyielding, there was great difficulty in keeping the chairs firmly attached to them; and, there being an entire absence of anything to act as an elastic cushion between the wheels of the vehicles and the ballast, a road laid with stone blocks was harsh to travel over, particularly at high speeds. Some of these disadvantages might, no doubt, be lessened; and in places where wood and iron are expensive, and where, on the contrary, stone is cheap, and where the speed need not be high, the expediency of using stone sleepers should not be lost sight of.

It was thought at one time that permanent way could not be made too rigid, and a short length of railway was once laid with wrought-iron rails in chairs firmly bolted down on a bed of solid rock. The result, however, was that in a short time the rails, chairs, and fastenings were seriously damaged. The fact is, that the surface of the rails pressed by the wheels is exposed to extremely high

crushing strains; and, moreover, the parts of a railway and of the rolling stock are not made so mechanically accurate in shape nor so close fitting as to avoid a succession of more or less violent blows, which act on the parts of any permanent way laid on a rigid unyielding bed like the blows of a hammer on any material interposed between it and an anvil, and quickly destroy it. Experience seems to show that where wood is attainable, and is not exposed to special local drawbacks, it forms by far the most suitable material for sleepers.

Wood is used for sleepers in two ways—viz. as cross sleepers (Figs. 22 and 23, p. 58), and as longitudinal sleepers (Fig. 31, p. 76). The ordinary size of cross sleepers now used is 9 ft. long, 10 in. wide, and 5 in. thick; but these dimensions of width and thickness are exceeded on lines such as the Metropolitan and Metropolitan District Railways, on which the traffic is abnormally heavy. The wood usually employed in England and in Europe generally is Dantzic or Memel fir, but occasionally pitch pine and oak are used; and both of these—particularly the latter—are superior to fir; but the cost of them, as compared with that of fir, is generally too great to permit of their being extensively adopted. In other countries many descriptions of hard woods, such as teak, mahogany, and oak, are employed for sleepers, with the best results.

Sleepers should be of the soundest timber, with little or no sap, and they should be sawn true to form, at least at their lower side. Sometimes sleepers are allowed to be round at the top, and in this case a flat place has to be truly adzed or planed as a seating on which the chairs may firmly rest (as shown by the horizontal dotted line at the top of fig. 33). It is far better, however, that sleepers should be cut out of trees large enough to permit

of their being rectangular in section (fig. 34), and with little or no sap wood in the section.

Some years ago sleepers triangular in section (fig. 35) were used, with the advantage that in this way two sleepers of the required base could economically be cut out of a smaller log than if the sleepers were rectangular in section; but as it was found that more and more size and strength had to be given to sleepers under the increasing loads on locomotive driving wheels, and as the necessity for a thoroughly steady bearing surface for the sleeper in, as well as on, the ballast, became more and more apparent, the triangular sleepers were gradually given up.

Fig. 33.
Half-round sleeper.

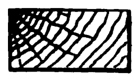


Fig. 34.
Rectangular sleeper.

Fig. 35.
Triangular sleeper.

Cross sleepers ought to be placed at such a distance apart as is proportioned to the area of the sleepers, the strength of the rails, and the loads to be carried. With the ordinary rails of 75 to 80 lbs. per yard, used in this country, and with the heavy loads on the driving wheels of English locomotives, the distance from centre to centre of cross sleepers of the ordinary size is generally 3 feet, and rarely exceeds 3 feet 3 inches. On each side of the joints of the rails the sleepers are put closer together (2 feet apart from centre to centre), in order to afford extra support to the rail at its weakest place.

Longitudinal sleepers, as used in this country, are balks of timber, about 12 in. by 6 in., which are laid beneath and parallel to the rails, and give them continous support. The timbers are connected at intervals by transoms about 4½ in. by 6 in. slightly notched into them,

and secured to them by iron bolts passing through both the longitudinal timbers, or by iron knees. When the longitudinal timbers are of soft wood, thin pieces of hard wood, such as elm or oak, should be laid with the grain of the wood at right angles to the direction of the rail, between the rail and the longitudinal sleeper, in order to prevent the rail from being forced into the longitudinal timber, which is apt to happen when the grain of the wood is parallel to the rail.

The continuous bearing which the longitudinal sleeper gives to the rail is a great advantage in many ways, and it enables a lighter rail to do the work of a heavier one. Thus on the Great Western Railway a rail weighing 62 lbs. to the yard has carried for many years, and is now carrying, the heaviest traffic; while other companies, and the Great Western Company itself, when using cross sleepers, use a rail weighing from 75 to 85 lbs. per yard. Apart from the saving of iron in the rails, the longitudinal system is safer than the cross sleeper road in the event of the wheels leaving the rails. In such an event, the wheels on the cross sleeper road drop into the ballast between the sleepers, and then bump heavily over one sleeper after another, breaking the couplings and springs, and seriously damaging the carriages, while with longitudinal sleepers the wheels of the vehicles which have left the rails can run, and often have run, along on the top of the longitudinal timbers comparatively smoothly, and without serious damage to the rolling stock, until the train has been stopped.

Against these advantages must be set certain drawbacks. The timber used for longitudinal sleeper roads must be of larger scantling, and therefore more expensive per cubic foot than the smaller timber used for cross sleepers. The longitudinal timbers are not only more

cumbrous than cross sleepers in laying the road in the first instance, but, what is of more importance, they are awkward in the ordinary repairs of the line. If a cross sleeper is damaged, or is found to be defective in quality, it is easily replaced without disturbing the rail or the adjoining sleepers; but in the longitudinal system, to replace a sleeper involves taking up the rail and the temporary stoppage of the traffic. The question of convenience for repairing and renewing the permanent way quickly is one of very great importance on heavily worked lines. The efficient drainage of the longitudinal sleeper road presents, perhaps, some slightly greater difficulty than that of a road with cross sleepers, but there is no real reason why one system should not, with ordinary care, be as well maintained and drained as the other.

On narrow gauge lines the longitudinal system involves an excess in the quantity of timber, but the reverse is the case on broad gauge lines, where the saving in quantity pays for the excess of cost in respect of the quality of the timber used. The sizes given above for cross sleepers and for longitudinal sleepers are those which have been found best for the heavy traffic of this country; but where the loads are lighter, the sleepers (as is the case with the other parts of permanent way) may be made of proportionately smaller dimensions. It is a question whether for light railways, even on a narrow gauge line, longitudinal sleepers may not be economically used where timber is cheap, as there can be no doubt that this facilitates the use of a rail with a small sectional area.

Sleepers fail, from rotting in the ground, from the chairs, or (in cases where there are no chairs) from the rails being gradually driven into them, and splitting asunder the fibres of the wood, and, in many foreign countries, they are destroyed by white ants or other

insects. As regards the first cause of failure, too much attention cannot be given to the drainage of the ballast, and even this is of little use unless the wood be in the first instance sound and well selected. There are several chemical modes of treating wood, such as creosoting, kyanizing, or treating it with sulphate of copper, which increase its durability under moisture, and act as a protection against insects. In these processes the chemical preservative compound is forced by pressure into the pores of the wood. In creosoting as performed in this country the timber is put into an air-tight receptacle, and the creosote is forced into the wood transversely to the fibres. Great pressure is often necessary to effect this thoroughly, and it frequently happens under this system that if the creosoting be carelessly done, the creosote does not penetrate to the centre of the log. In the sulphate of copper process, when it is carried out soon after the trees are felled, and when the natural moisture of the tree is still perfect, a solution of sulphate of copper is forced in at the end of the log by hydrostatic pressure, and the solution, driving the sap out before it, finds its way lengthwise of the fibres from one end of the log to the other.

There are several descriptions of iron sleepers used especially in countries where timber is scarce or where insect life or atmospheric conditions render the use of timber inadmissible for sleepers. The iron sleepers, which are almost always combined with the chairs, will be considered under the head of Chairs, which is the next subject to be considered.

On the old horse tram-roads instead of rails flat plates with flanges were used, and these plates were spiked down to longitudinal timbers. From these plates came the appellation 'Plate-layers,' which is still in use for

the men who attend to the laying and maintenance of the permanent way. Subsequently the flange was put on the wheels instead of on the plates, and a flat-footed rail was substituted for the flat plates, and this in turn, after the trial and abandonment of the fish-bellied and other forms of rails, gave way to the double-headed rail.

The use of the double-headed rail necessitated the employment of some sort of support, to secure it vertically and horizontally in its proper position; for a rail of the double-headed section is by reason of its form deficient in stability, and cannot well be secured directly to sleepers by any bolts or fastenings passing through it. The appropriate name of 'Chair' was given to the support introduced between the double-headed rail and the sleepers; chairs fulfil not only the purpose of supporting and holding the rail, but also of spreading the weights carried by the wheels of vehicles over a considerable area of the sleeper. The double-headed rail being intended to be reversed, so that both top and bottom may be used in turn, it is necessary that the under and unused side should be kept as free as possible from damage until it is required to be turned upwards. Cast-iron chairs should fulfil this purpose, in addition to holding the rail securely in its place. The rail is placed in the chair (fig. 36), and a wooden taper wedge or key is driven between the side of the rail and the hook-like side of the chair.

This wedge is intended to hold the rail firmly down on its seat in the chair as well as to hold it sideways in its position, it being of great consequence to check any rising and falling of the rail when the engine-wheels are passing over it. If the rail is free to move to a small extent vertically, the malleable rail, which is softer than the cast-iron chair, is hammered by continual blows from

the wheel, and becomes indented to the shape of the seat of the chair. When such a rail is turned over, the surface is found to have abrupt depressions in it wherever it has rested on the chairs, and when traffic passes over the indented surfaces the wheels of the vehicles inflict a series of blows as they pass over the hollow places. Thus an in-

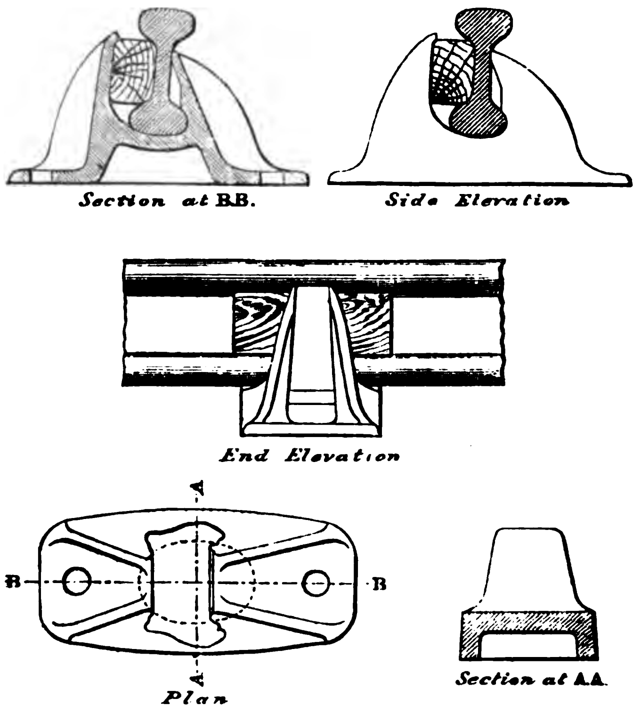


FIG. 36. Cast-iron chair for double headed rail.

dented rail when turned is not only extremely unpleasant to travel over, but it also quickly wears out. So great is the difficulty of keeping the under surface of the rail uninjured, that some engineers have discarded the idea of turning the rails, and have made the double-headed rail with heads of unequal size, the smaller and lower one

being only made large enough to give sufficient strength to the rail as a girder, the rail not being intended to be reversed. In order to prevent the damage to the underside of the reversible rail, the chair has gradually been made larger and heavier, so as to afford a greater bearing area, and, whereas 20 lbs. used to be the weight of ordinary chairs, at the present time chairs weighing 50 lbs. are being laid down.

To avoid injury to the under side of the rails, chairs have been used, on the North-Eastern and on some other lines, with a thin block or cushion of wood let into the seat or sole of the chair for the rail to rest upon. The wood preserves the rail, but it is said that it makes a somewhat loose road if not carefully attended to, from gradual alteration in the bulk of the wood resulting from the compression due to the weight and to shrinkage from atmospheric causes.

Another expedient for meeting the difficulty was adopted in the bracket chair used on the West Cornwall Railway, the Llynvi and Ogmore Railway, and other lines. This chair (fig. 37) consists of two distinct pieces of cast-iron so shaped as to fit under the upper shoulders of the rail, and extending downwards about $\frac{1}{4}$ of an inch below the bottom of the rail. A wrought-iron bolt passing through the rail unites the two sides firmly together, and the chair is bolted or spiked down to the sleepers in the ordinary way on one side, while on the other side the bolt or spike passes through a slotted hole in the chair,

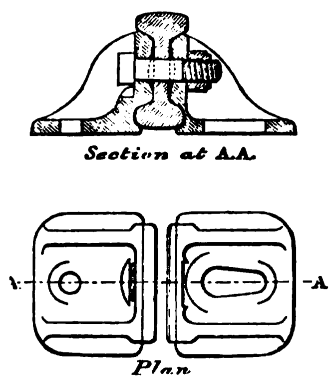


FIG. 37. Bracket chair.

the slot being at right angles to the direction of the length of the rail, and long enough to allow the half chair to be moved sideways about two inches. When a rail has to be taken out, the cross bolts are removed and the bolts in the slots in the half chair slackened; this having been done, the half chairs on one side of the rail can all be moved away from the rail, the rail taken out and turned, or a new rail put in. There are certain inconveniences more or less important attendant on the use of the bracket chair, but they may to a great extent be surmounted by foresight and management, and do not probably outweigh the undoubted advantages which the bracket chair possesses. These are, a great reduction in the weight of the chairs without any corresponding reduction of bearing area on the sleepers (the two half chairs weighing together only 18 lbs. and the bolt 1 lb. against the far greater weights of ordinary chairs given above), the very efficient support given to the head of the rail, the reduction in the height of the rail above the sleeper by the thickness of the bottom of the ordinary chair, the consequent reduction of the leverage of the sideways strains on the chair and on the ballast, the preservation of the lower surface of the rail from injury, and the saving of the cost and the avoidance of the many objections to the use of wooden keys.

Under the head of chairs it is necessary to allude to the various descriptions of cast-iron sleepers which may be said to be both sleeper and chair in one. The best known of these are the bowl or pot sleepers (fig. 32, page 76), which are ordinarily made of a domical shape of cast iron, from $\frac{5}{8}$ in. to 1 in. thick, the bowl being about 23 in. diameter at its base, and about $5\frac{1}{2}$ in. high. Pot sleepers generally have the chair cast on them, the rail being fastened in the chair in the usual way with

keys. In laying the line with pot sleepers, the ballast is made into little heaps where the sleepers are to be placed, large enough to roughly fill the interior of the bowls, which are then placed on the heaps; the final packing is effected by ramming fine ballast into the interior of the bowl through holes left in the upper surface of the bowl. The gauge is maintained by cross tie-rods attached to every pair, or to every other pair of bowl sleepers. The use of iron sleepers is advisable in countries where timber is scarce or exceptionally liable to destruction or decay; but the form of chair in which the fastening of the rail depends on a wooden key is, as has been already explained, objectionable in all cases, and more particularly so in hot climates, where pot sleepers are chiefly used.

A plan has been introduced of casting the bowls in an elliptical shape, with two jaws of a chair on one side, and a third jaw on the other side of the bowl, equidistant between the two opposite jaws (fig. 38). A key is driven between the rail and the centre jaw, which slightly bends, or springs,

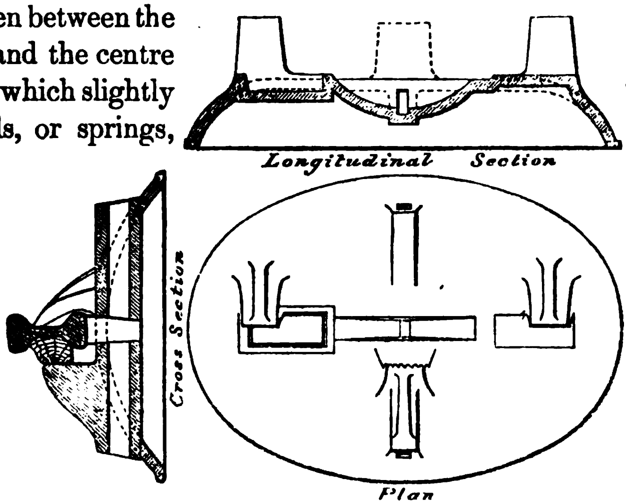


FIG. 38. Elliptical pot sleepers.

the rail, and the resilience of the strained rail keeps the

key tight. This system has the advantage of affording a large amount of bearing for the rail on the bowl, but it has been suggested that the bending of the rail, although it is very slight, may be injurious to it. The pot sleeper may be made to carry a wood cushion on which the rail may rest; such an arrangement is shown on the left side of the plan and longitudinal section (fig. 38).

Sleepers have been made of wrought iron, following the general features of longitudinal or cross sleepers of wood, having chairs placed on them and secured to them by bolts; and the pot sleepers also have been made of wrought iron pressed to a form like the buckled plates often used for the platforms of bridges. The advantages of wrought iron over cast iron, in its greater strength and toughness, which render it possible to make the sleepers of equal strength with much less metal, are obvious, and the saving of weight and consequent expense of carriage is often important. All these matters, however, resolve themselves very much into questions of economy, and it is to be remembered that in order to compete with the first cost of cast-iron bowl sleepers, wrought-iron sleepers, owing to the greater cost of the material, have to be made extremely thin. They are thus liable to lose their form, and consequently their strength; and in a material so liable to rust as wrought iron, oxidisation may cause serious difficulties, or may entail expense in endeavouring to guard against it.

We now reach the subject of the rails.

The double-headed rail (fig. 28, p. 75) is that which is more generally used in England, in France, and on the older continental railways. It was introduced upwards of forty years ago, and is still adopted for most new lines in this country, though elsewhere the flat-bottomed rail is often used in preference. The double-headed form possesses

certain undeniable advantages. The metal in it is disposed advantageously so far as vertical strength is concerned; the rails are easy of manufacture; they can be reversed, so that when one face is worn out the other can be used; and they can be efficiently connected at their ends.

On the other hand, this form of rail has little lateral stiffness, and requires extraneous sideways support. It possesses in itself but a small base, and requires chairs not only to support it vertically, but also to spread the weight carried by it over a larger area than the base of the rail itself affords. These last two defects render it necessary that in using a double-headed rail the expense of chairs of some sort must be incurred, and the expense of these may be taken at from 250*l.* to 400*l.* per mile of single line of way. Against this considerable expenditure must be set the advantage of reversing the rail; but no thoroughly satisfactory means of keeping the under side of the rail uninjured have yet been found, or at least none which have secured the general approval of engineers, or have stood the test of experience for any considerable period. Any comparison of the two forms of rails must thus be between a rail which cannot be reversed but which requires no chairs, and a reversible rail which must be supported on chairs, but which is generally injured before it can be reversed, and which rapidly wears out after being turned.

It is sometimes thought that chairs are a necessity for the purpose of securing all rails laterally, and in this country they are almost universally used. Possibly where the weights on the wheels of the locomotives are inordinately great, where the speed is high, and where trains are extremely frequent, interfering with the efficient maintenance of the fastenings, chairs may be desirable,

but experience, particularly in foreign countries, seems to show that no real difficulty exists in thoroughly securing a flat-bottomed rail having a base 5 in. or $5\frac{1}{2}$ in. wide, and in using such a description of permanent way for a very considerable and rapid traffic. On many lines flat-bottomed rails are secured entirely by spikes or dogs (see pp. 103 and 104), but this mode of fastening scarcely gives the rail a fair chance, and ought not to be employed when heavy weights are conveyed on the railway at high speeds. It is extremely difficult to keep spikes from slightly drawing out of the timber, and, owing to the smallness of the transverse dimension of the rail as compared with that of a chair, play between the rail and the sleeper is more to be deprecated than the same movement between a chair and a sleeper. A common mode of fastening is to have two fang-bolts (fig. 39) near each end of the rail, and to have spikes or

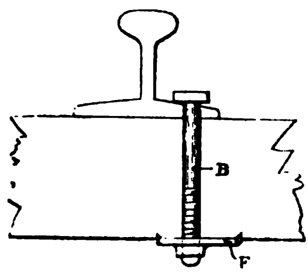


FIG. 39. Fang-bolt passing through rail. B. Bolt. F, Fang.

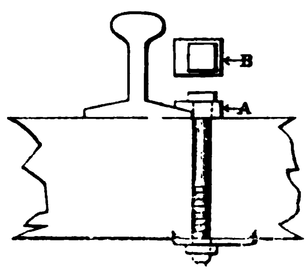


FIG. 40. Fang-bolt and clip. A. Elevation of clip. B. Plan of clip.

dogs at the intermediate sleepers. Except on the score of economy, it is difficult to see why fang-bolts should not be used at all the sleepers, and the saving by using spikes or dogs is but small.

A good fastening consists of fang-bolts, with clips so shaped as to fit the upper surface of the foot of the rail (fig. 40). This plan obviates the necessity for making

holes in the foot of the rail, which diminish the strength of the rail to a serious extent. It is also desirable, other things being equal, to apply the fastening near the edge of the rail, so as to have as large a leverage as possible to counteract the tendency of the flanges of the wheels to thrust the rails over outwards.

To return to the subject of the form of rails, we have to consider the two types, viz. the 'Vignoles' rail (fig. 29, p. 75) and the 'bridge' rail (fig. 30, p. 75). The flat-bottomed 'Vignoles' rail differs from the doubled-headed rail in possessing in consequence of its wide foot lateral strength in itself to resist the outward thrust of the wheels without the support of chairs, while at the same time it possesses as much vertical strength. Some of the advocates of this flat-bottomed rail claim for it that it can be made stronger vertically than the double-headed rail, because, as it is not to be reversed, hard granular iron can be put in the head to resist compression, and tough fibrous iron in the foot to resist tension, while in a reversible rail the iron must be the same in both head and foot. This claim, however, cannot be allowed, as the rail acts as a continuous girder, and both the head and foot are alternately in compression and tension.

A very important question, in comparing the double-headed rail and the 'Vignoles' rail, is the bearing area on the sleepers afforded by each directly or indirectly: for the failure of wooden sleepers from the wood being crushed is one of the many sources of expense in the maintenance of permanent way. When the flat-bottomed rail is laid on cross sleepers, the bearing area is the width of the sleeper multiplied by the width of the bottom of the rail. In this case the supporting area at each end of a sleeper 10 in. wide is rarely more than from 50 to 60 square inches, while with a chair the bearing area can be made

as much larger as may be desired. If, however, the cross sleepers are accurately cut to fit the base of the rail, and the timber of the sleepers be good, the area of 50 square inches ought to be quite enough, more especially as the rail is laid crossways to the grain of the wood. In the case of some of the heavy chairs now being used, the supporting area is upwards of 100 square in., but these chairs are probably made of this great size less for the sake of the sleeper than to preserve the under surface of the reversible rail.

The 'Bridge' rail takes its name from the resemblance which the cross section bears to the elevation of a bridge with abutments and an arch spanning an opening. It was designed to be used in combination with the longitudinal sleeper, but has been laid in Ireland and Canada on cross sleepers, though it is not suited for this latter purpose. The principle of the bridge rail is that it should possess a broad base and sufficient lateral strength, but that it need not have great vertical stiffness, as it was intended to be continuously supported on longitudinal sleepers. Thus, whereas a rail 4½ or 5 inches high, weighing from 75 to 85 lbs. per yard, is found to be required with cross sleepers 3 feet apart, the height of the bridge rail used on the Great Western is only 2¾ inches; and its weight is only 62 lbs. per yard, even where the traffic is heaviest. Another reason why a lighter rail in the bridge form will do the work of a heavier rail of the ordinary section, is that the edges of the rail (against which much stress comes from the flanges of the wheels) are admirably supported by the two vertical webs. An ordinary rail often fails from its overhanging edges being crushed and bent downwards, and a point which is therefore always aimed at in designing the form of the ordi-

nary double-headed or flat-bottomed rail is to give as much vertical support as possible to the edges of the flanges. In the bridge rail there is no portion of the head overhanging the web, and thus the danger of unsupported edges giving way is avoided.

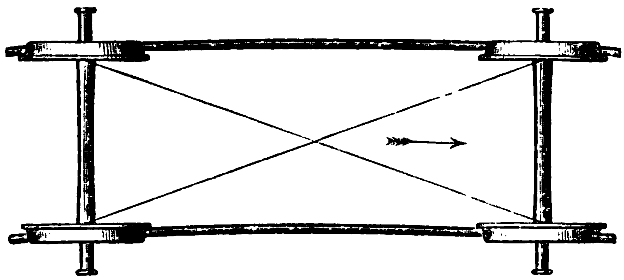
The top surface of a rail should be so designed that its shape will correspond to the shape of the tires of the wheels which are to run over it, so that the largest possible amount of supporting surface may be afforded to the wheel. The flat portions or treads of the wheels of ordinary railway rolling stock are, it must be remembered, not cylinders, but portions of cones, and the wheels are fixed to the axle, which revolves with them, unlike the wheels of road vehicles which revolve on a fixed axle. The object of the conical form is that, when in passing round curves the carriage is thrown outward by centrifugal force, the outer wheels may run on the rail where the diameter of the wheel is greater, and the inner wheels where the diameter is less. Thus, it was intended that although the outer and inner wheels should both revolve at the same speed, the differences of length round a curve measured along the two rails should be represented by the different circumferences of the two wheels touching the rails. Whether this really takes place in practice or not is a point which will not now be discussed; but the fact remains that the wheels of railway rolling stock are almost invariably made conical, and it follows that it is desirable that the vertical axis of the rail should be placed at right angles to the surface of the cone. In a road laid with a double-headed rail, the chairs are therefore so made that when the rail is in the chair it is in an inclined position (fig. 36, p. 84) to suit the inclination of the cone of the wheels, while when the flat-bottomed rail is used,

the sleepers are adzed in the case of cross sleepers, or sawn or tilted in the case of longitudinal sleepers, to attain the same result.

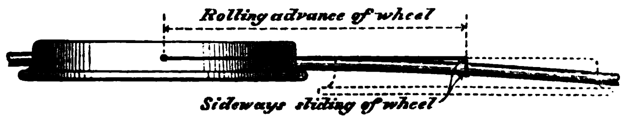
As regards general principles governing the shape of rails, it must be borne in mind that rails are destroyed mainly by the rubbing and sliding of the wheels on the rails as distinguished from their rolling. This destructive rubbing is chiefly due to two causes: 1. That wheels of railway rolling stock are fixed to the axle. 2. That in almost all railway rolling stock the two or more axles of each vehicle must always remain parallel to each other.

If two wheels of equal diameter are fixed to one axle and made to roll on a plane, as both wheels must revolve at the same pace, they must either both advance equally and the pair must travel in a straight line, or else one or other of the wheels must slip. In going round curves the path travelled by the outer wheel is longer than that travelled by the inner wheel, and it is obvious that with wheels fixed to the axle, unless their diameters are different, constant circumferential slipping must take place. The conical wheel was, as I have said, meant to obviate, or at least to decrease, this evil, as the centrifugal force, it was thought, would push the wheels outwards from the centre of the curve, causing all the outer wheels to revolve on a larger circumference and all the inner wheels on a smaller circumference. Practically this remedial action takes place to a very limited extent, because, in consequence of the axles of carriages on railways being kept parallel to one another in a rigid frame, all the axles cannot adjust themselves radially to the curve, and when the leading wheels of a carriage are rolling forward and bearing sideways against the outer rail of a curve, the trailing or following wheels of the same carriage are rolling forward parallel to the leading wheels, and are bearing sideways against

the inner rail (see fig. 41). The evils due to the wheels being fixed to the axles are therefore not obviated by the conical wheels. The best form for the tire of a railway wheel is no doubt cylindrical, and the wheels, or at least one wheel on each axle, ought to be made to revolve on the axle, so that when a vehicle is travelling round a curve the outer wheel may revolve more rapidly than the inner wheel, and circumferential slipping be avoided. Fixing both wheels firmly on the axle no doubt



Plan of two parallel axles with their wheels going round a curve.



Enlarged plan, showing the course of a wheel on a non-radial axle going round a curve.

FIG. 41.

simplifies carriage and engine building, and no great company has as yet used wheels loose on the axle except experimentally, but it is much to be wished that the builders of rolling stock would turn their serious attention to designing wheels to rotate on fixed axles. The other cause of destructive rubbing is still more serious. In going round curves, as the axles in each vehicle remain parallel to one another, they cannot both set themselves radially to the curve, and consequently each wheel, instead of rolling tangentially along the rail, lies

frequently diagonally across it (see enlarged plan, fig. 41), and as it rolls onward has at the same time to be dragged or made to slide sideways on the rail, causing a very destructive abrading action on the rail.

The head of the rail is generally from $2\frac{1}{4}$ to $2\frac{3}{4}$ in. wide, and the width of the head supporting the weight does not exceed $1\frac{1}{4}$ in., while the length of the rail directly supporting the weight, allowing for the compression of the rail and the flattening of the wheel tire, has been variously estimated at from $\frac{1}{8}$ to $\frac{3}{8}$ of an inch. If the weight on a driving wheel be 8 tons, it is evident that the metal in rails is in this way subjected to a stress far beyond what would be considered prudent when iron or steel is used for other purposes, and it is not surprising that imperfectly made rails are absolutely squeezed out of shape. Indeed, in practice the wheels squeeze and wear down the rails, till the rail section approximates to the general form of the wheels. It must also be borne in mind that wheel tires which have been long in use become hollow in the tread, and that any sideways movement of such wheels on the rail brings very small areas of surface into contact, and great local pressures are thus developed.

An important point rightly aimed at in the design of a good rail is that the top and bottom of the rail should be as nearly as possible of equal strength, considering the rail as a continuous girder, with the tensile and compressive strains due to the loads that are carried by it alternately exerted on the bottom and top flanges. Rails usually, however, wear out, not from the work they do, considered as girders, but from the abrasion caused by the weight of the driving wheels sliding on them.

From the above considerations two things seem to be of great importance, viz. :—

1. To reduce the weight on the driving wheels as much as possible.

2. To have as hard and homogeneous a metal for the head of the rail as can be given consistently with proper tensile strength.

Little is being done to carry out the first desideratum; indeed of late years the weights on driving wheels have on most railways been increased as greater tractive power is required. On the other hand, great attention is being given to the quality of metal used for rails; and both engineers and manufacturers are constant in their endeavours to arrive at an admixture of metal and at a process of manufacture which shall carry out the second requirement above mentioned. Unfortunately, as the metal is improved, the increase of weight on the wheels seems to counterbalance the improvement.

These considerations naturally lead to the comparison of iron and steel as the material for rails; and in considering the distinctive characteristics of the two materials, the mode of manufacture of each must be borne in mind.

An iron rail is made by rolling together a number of separate pieces of iron, which, when placed ready for rolling, are called the rail pile. It is of much consequence in designing rails, or indeed any other form of rolled iron, that all parts of the section should be such as to be suitable to being rolled at one or nearly one intensity of heat. Great differences of thickness in the section are to be avoided as much as possible, for the heat which is suitable for the thick portions may be so high as to cause the thin portions to be unduly yielding, and *vice versâ.* A rail pile (fig. 42) is composed in different ways according to the specifications of engineers and the price of the rails. Speaking gener-

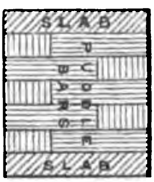


FIG. 42. Ordinary rail pile.

ally, the pile is made about $8\frac{1}{2}$ in. wide, and 9 in. high, and if the rail to be rolled is a double-headed rail it is built up as follows. The top and bottom of the pile which will hereafter form the two heads of the rail consist of slabs of hard hammered iron $8\frac{1}{2}$ in. wide and $2\frac{1}{2}$ in. thick, and the space between the slabs is filled up with puddle bars $\frac{3}{4}$ in. thick, which may either be as wide as the pile, or may be put together so as to break joint. The pile is heated in a furnace to a welding heat, and hammered or rolled into a solid lump or bloom, about 5 in. wide and 6 in. deep, which is again heated to a welding heat and rolled into the finished rail.

This mode of manufacture can never make a really homogeneous rail. It is not merely that the structure of the rail being made up of a number of plates requires a large number of welds to be made, but the top and bottom slabs are themselves the result of a similar process of hammering and welding, a process which begins from the time the iron leaves the puddling furnace. The efficiency of all these welds depends on the absence of any cinder in the iron, and on its being properly hammered at a proper heat. Thus even with the greatest care in manufacture wrought iron is a material the reverse of homogeneous, having fibres and a grain in it like wood. It is consequently ill adapted for high tranverse compressive strains, and worse adapted for resisting violent rubbing, which can destroy it fibre by fibre. It is true that wrought-iron rails can be and have been made so well, in spite of the inherent defects of the material, as to stand the wear and tear of the traffic for very many years. Instances are well known of wrought-iron rails having lasted upwards of twenty years, under heavy traffic; but in such cases the iron has been of a superior quality, and great care has been taken with the manufacture. Pro-

bably if such rails had to be made now, the price of them would not differ materially from the price of steel rails.

Steel, as used for rails and properly manufactured, possesses most of the good qualities and none of the bad qualities of wrought-iron. It can be produced at a moderate cost. It has higher tensile and compressive strength, but above all it is homogeneous. The steel is fused into one molten mass, and then cast into ingots from which the rails after further hammering are rolled. There are thus no welds in a steel rail. The whole rail is of the same texture, and is not susceptible of lamination and destruction in detail. Care indeed is required, in manufacturing steel for rails, to avoid brittleness and to insure toughness; and it is to be borne in mind that in scarcely any material used for mechanical purposes are these qualities more dependent on niceties of admixture and manufacture. But no difficulty now exists in making thoroughly satisfactory steel rails; although when they were first introduced, and the delicacy of manufacturing steel was not appreciated, there was some uncertainty in the quality of metal which would be turned out from a casting.

Under these circumstances, steel is evidently destined to supplant iron as a material for rails where the traffic is heavy; but where the traffic is extremely light it is possible that the extra durability may be purchased at too dear a rate, when the compound interest on the first cost is taken into account.[1]

From the introduction of railways to the year 1847, rails were laid without any rigid connection between them endways, and the rails were simply placed one against the other, in a chair made of extra size for the purpose, and

[1] Since this was written we have seen the price of steel rails as low as the price of wrought-iron rails of good quality.

called a joint chair (fig. 43). Under such conditions the ends of the rails could slide up and down past one another to a small extent, and each wheel as it passed from one rail to another, having already depressed the rail which it was leaving, had to mount on to the next rail, which was not depressed, as on to a slight step. Thus a series of blows occurred, and these blows naturally caused the ends of the rails to rapidly wear out. In 1847 the system of uniting the ends of the rails by fish-plates was introduced, and it is now universally adopted. The object of the fish-joint, which derives its name from the nautical term 'fishing,' for mending a broken spar by lashing timber on each side of it, is that it should be impossible for one rail to rise above the other, and that the joint should be made as strong vertically as other parts of the rail, which would

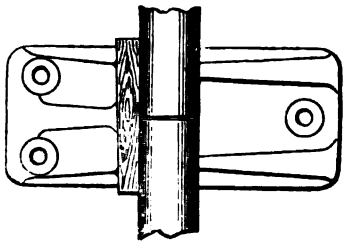


FIG. 43. Joint chair.

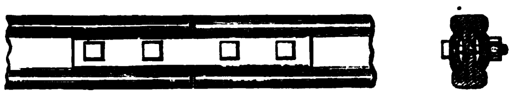


FIG. 44. Fish-plate for double headed rail.

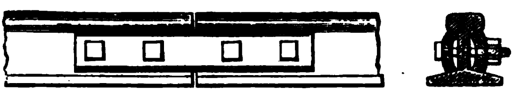


FIG. 45. Fish-plate for flat-bottomed rail.

thus, as a whole, become a continuous girder. Joint chairs could thus be dispensed with, as the joint could be placed intermediate between cross sleepers. In the fish-joint (figs. 44 and 45) a plate of iron, called a fish-plate, which is about 1 in. thick, is placed on each side of the web of the rail, but not touching the web; the upper and lower edges of the fish-plates are made to fit accurately the sloping sides of the head and foot of

the rail, and bolts which are called fish-bolts pass through the rail and the two fish-plates. The fish-bolts draw the plates together, and tighten the edges of the fish-plates against the rail. The rail at the fish-joint, though very strong, is, from want of depth of the fish-plate, not so stiff as other parts of the rail, and therefore the cross sleepers on each side of the joint should be brought nearer together than at other places, and the bearing reduced to as short a space as the length of the fish-plate will allow. To give extra vertical stiffness to the joint the fish-plates are sometimes made deeper than the rail and to project downwards below the bottom of the rail.

An objection attaching to the bridge rail is that there is a difficulty in uniting two rails endways in as satisfactory a way as is done by the fish-plates and bolts of the other two forms of rail. The ordinary fish-plates are not suited to the bridge rail, as they would get in the way of the flanges of the wheels, but there cannot be any real difficulty in designing an efficient mode of junction, and probably the reason why it has not yet been carried out is that with the longitudinal sleeper road the joints are not so weak as with the cross sleeper road, and the necessity of a better fastening than is now adopted has not been found imperative. The fastenings usually adoped for the ends of the bridge rail are shown in fig. 46, but they are manifestly inferior to the fish-joint.

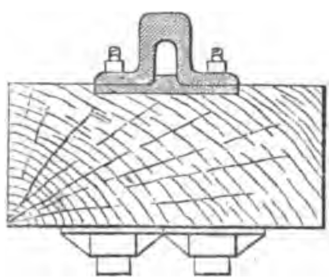


FIG. 46. Joint plates for bridge rail.

The efficiency of the fish-joint depends on the fish-plates being kept tight against the rail, but the nuts of the fish-bolts are apt to shake loose with the jar of passing trains, and have frequently

to be screwed up. To counteract this tendency as much as possible, the rubbing surfaces of the heads and nuts of the bolts should be made slightly concave, so that they grip the metal of the fish-plate near their periphery, and the thread of the screw should be at rather a flat pitch. There are several devices of spring and cutting washers for the purpose of preventing the fish-bolts from becoming slack, but none of these have come into extended use. In practice the plate-layers have constantly to examine the fish-bolts and to screw them up as may be found necessary. It is thus desirable that in some way the bolt or the nut should be held firm and not be capable of being turned round, as otherwise, to screw them up, both bolt and nut must be held by spanners; fish-plates have therefore been introduced of various designs to effect this purpose. In some such arrangements one of a pair of fish-plates has square or oval holes instead of round holes, the fish-bolts having square or oval necks near their heads (fig. 47); other fish-plates have an indentation rolled in them into which the head or nut of the bolt fits, and is so held fast, while the other end can be turned; another arrangement is to have one fish-plate tapped with a screw to fit the fish-bolts, and nuts are then dispensed with.

FIG. 47.
Fish-bolt with square shoulder.

In all cases allowances should be made for the expansion and contraction of the rails from changes of temperature, by having the holes through the rails about $\frac{1}{8}$ of an inch larger than the diameter of the bolts, or by having the holes in the rails made oval in shape.

The next subject to be considered is that of the fastenings by which the rails or the chairs are attached to the sleepers. These fastenings are spikes, trenails, wood screws, or fang-bolts.

Spikes (fig. 48) are cylindrical iron bars with heads, and they are driven into a hole bored with an auger in sleeper. The hole is made slightly smaller than the spike, which is retained in its position by the elastic grip of the fibres of the wood closing on the spike after it is driven, but spikes are at best apt to become loose from the yielding and shrinking of the timber. It is of great consequence that the chair should be held very firmly down on the sleeper, and that the spikes should accurately fit the holes in the chairs, for if they are even slightly too large the chair will be split, and if they are too small the chair will be loose on its bearing, and will gradually rub away and destroy the spike.

FIG. 48. Spike.

Trenails (fig. 49) are wooden spikes so compressed by machinery as to drive all moisture from them before they are driven into the sleepers. When they have been driven into their place their tendency is to swell by absorption of moisture, and they are thus held fast in their places. Trenails, however, become rotten, and they are deficient in strength to resist the shearing action of the chair sliding on the sleeper. For this reason it is not safe to rely on wooden trenails alone, though when they are sound they are no doubt well adapted for holding the chair firmly down on the sleeper. Where trenails are used now-a-days, spikes are generally used with them; and if a railway chair is held down by trenails, one at least of the fastenings should be an iron spike or fang-bolt. A combination of spikes and trenails is in use, known as the hollow compressed trenail (fig. 50). This trenail consists of a hollow cylinder of compressed wood, and the centre of the cylinder receives an iron spike. The trenail is first

FIG. 49. Trenail.

FIG. 50. Spike and hollow trenail.

driven into a hole bored in the sleeper, and then the spike, which fits the hollow in the trenail very tightly, is driven into the trenail. This further compresses the wood of the trenail and drives the fibres of the trenail into the fibres of the sleeper.

For fastening the flat-bottomed rail on to the sleepers, spikes which are rectangular in cross section, and which have large projecting heads extending about ½ an inch over the upper surface of the foot of the rail (fig. 51), are often used. These rectangular spikes go by the name of 'dogs,' or 'dog spikes.'


FIG. 51. Dog.

Wood screws (fig. 52) have been much used for holding down flat-bottomed rails. These are screws of iron, with large cutting threads on them, and act like ordinary joiners' screws. An objection to them exists from their being weak in the thread compared with the neck of the screw where it passes through the chair, and from the fact that the screw is dependent for holding strength on the small quantity of wood included in the thread of the screw. The oxidisation of the screws is also apt to cause decay in the contiguous timber, and thus to make the screws become loose, in which state they are only equal to inferior spikes driven in decayed wood. Wood screws used in hard wood sleepers are not so open to the above objections.


FIG. 52. Wood screw.

Fang-bolts (fig. 53) are perhaps in this country the most satisfactory mode of fastening in ordinary use. Fang-bolts consist of bolts long enough to pass through the sleepers, with a screw cut on the lower end to fit a wide flat nut, having on it fangs or short spikes, which imbed themselves in the lower side of the sleeper and prevent the nut from

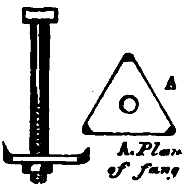


FIG. 53. Fang-bolt.

turning round. When the head of the fang-bolt is turned round at the top, the bolt is screwed into the nut and draws the chair or rail firmly down on to the sleeper, and the elasticity of the wood of the sleeper keeps the bolt tight.

The drawbacks of fang-bolts are that after a time, and particularly in moist countries, the screw of the fang-bolt becomes set fast by rust and cannot be turned round. In many cases, particularly in tropical countries, the sleeper shrinks from the heat of the sun and so decreases in thickness, and it becomes necessary in consequence to tighten up the fang-bolts, but it is found that owing to rust the screw cannot be turned, and in the effort to do so the fang-bolt is broken. This has been found so serious a defect that in many hot countries the use of fang-bolts has been discontinued and resort has been had to the old-fashioned spike.

A wedge spike (fig. 54) has been recently brought forward and seems to promise well. The spike is split, and the split receives a wedge which expands the two halves of the spike into the fibres of the timber of the sleeper, and causes the spike to assume with the wedge the shape of an iron dovetail which cannot be withdrawn, until the wedge has first been withdrawn. The mode of applying the wedge spike is to bore a hole through the sleeper and to insert below the sleeper an iron plate to hold up the wedge while the split spike is driven on to the wedge. The wedge can be withdrawn by a lever made for the purpose which grasps the bottom of the wedge and draws it as a dentist draws a tooth.

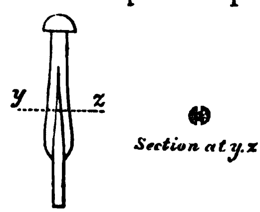


Fig. 54. Wedge spike.

The wedge or key by which the rail is held in the

chair has been already alluded to and shown in fig. 36, p. 84. The ordinary material for these keys is wood of hard description and good quality, which is generally compressed by hydraulic machinery until all moisture is driven out. When such a compressed key is driven into its position, it absorbs moisture from the air and expands, but in extremely dry weather wooden keys shrink and become loose in spite of the precaution of compressing them. Other descriptions of keys (such as wrought and cast iron keys) have been tried, but not with sufficient success to supplant the compressed wooden key. A wrought-iron key and a spiral key (fig. 55) are examples of these modifications.

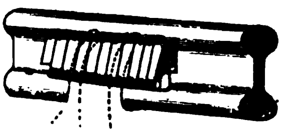


FIG. 55. Spiral key.

A good key should hold the rail very firmly, but should at the same time be capable of being slackened when required. The compressed wooden key seems to fulfil these requirements better than any others, but, considering how extremely important it is that no movement should take place, a wooden key is at best an imperfect contrivance for the purpose of holding the rail firmly in its position.

There are many other details connected with permanent way which, if time permitted, I should have liked to discuss. But I have laid before you some of the main facts and principles connected with the subject. The time at my disposal does not allow of my describing the practical modes of laying the road, but I ought to refer to one part of the plate-layers' work, namely, the laying a line of rails round a curve.

The centrifugal force of a train passing round a curve tends to make the flanges of the wheels on the outside of the curve press against the rail on the outside of the curve with a force dependent on the speed,

the curvature of the railway, and the weight of the vehicle.

To counteract the effect of centrifugal force the outer rail is elevated above the inner rail (fig. 56), and the

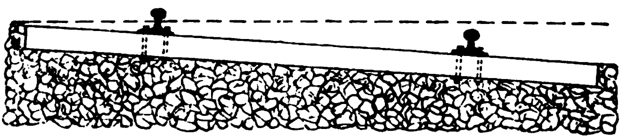


FIG. 56. Super-elevation of rails on curves.

amount of super-elevation (which is the term generally employed) of the outer rail must be determined by the consideration of the maximum speed at which trains will pass round the curve. Thus the outer rails of curves near large stations, where all trains travel at a low speeds, require little super-elevation, compared with the same curves between stations, where the speeds may be high. The rule for super-elevation usually employed is expressed by the formula—

$$E = W \frac{V^2}{1 \cdot 25 \, R}$$

in which

W = Width of gauge in feet.
V = Velocity in miles per hour.
R = Radius of curve in feet.
E = Elevation of outer rail in inches.

On very sharp curves an extra rail is often laid on the inner side of the inner rail of the curve (fig. 57), with only

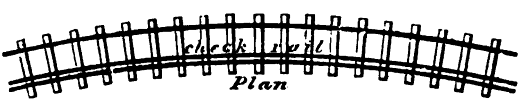


FIG. 57. Check rail on curve.

sufficient space left between the rails for the easy passage

of the flanges of the wheels. The extra rail, which is called a check rail, relieves the sideways pressure of the wheels against the outer rail, and prevents the wheels from mounting the outer rail.

The check rail, where the double-headed description of rail is used for the permanent way, is generally of the same section as the other rails, and is held in special chairs which hold both rails (fig. 58). Care should be taken that the distance-piece of the check rail chair be-

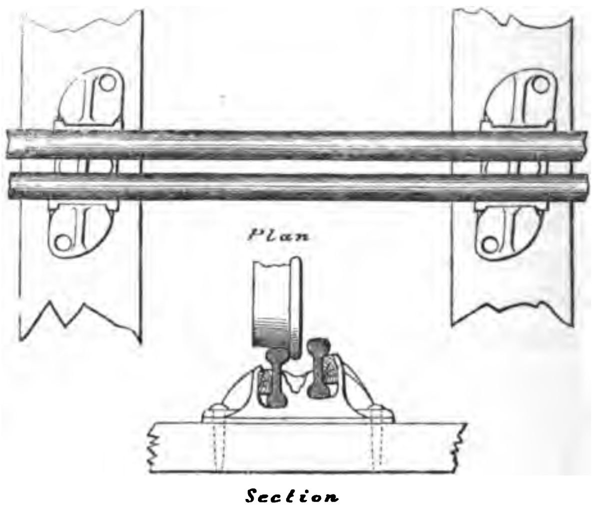


FIG. 58. Check rail with double headed rail.

tween the two rails should be kept low enough to allow the flanges of worn wheels travelling on worn rails to pass over it without striking it. Where flat-bottomed rails are used the check rail is often composed of a strong angle iron firmly bolted down to the sleepers (fig. 59). As an additional precaution against the wheels mounting over it, a check rail is frequently elevated about 1 in. above the adjoining rail on which the wheels run (see section in fig. 58).

When a sharp curve, say of 8 or 10 chains, joins a straight line, the necessary super-elevation of the outer rail is considerable, amounting perhaps to 4 or 5 inches, and the full amount of super-elevation is required at the commencement of the curvature of the line. In such cases the rail on the straight portion of the line joining the outer rail of the curve has to be elevated above its opposite rail for some distance prior to the commencement of the curve, so that the proper amount of super-elevation may be attained at the commencement of the curve without too sudden an incline on the outer rail, which would injure the springs and impart a lurching

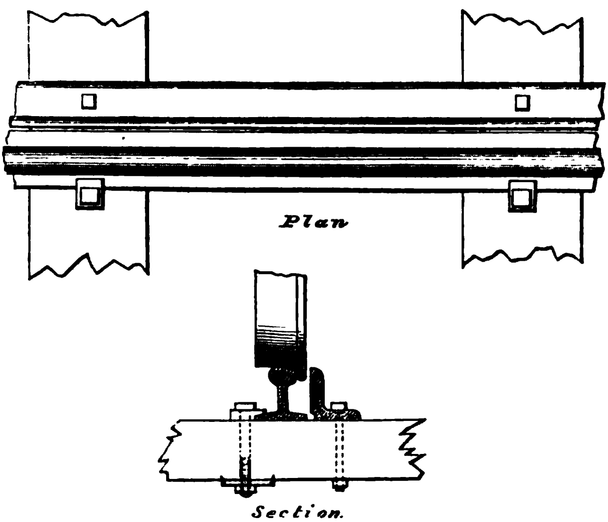


Fig. 59. Check rail with flat-bottomed rail.

movement to the carriages as they leave the straight part of the line and run on to the curve. In sharp reverse or S curves, it is desirable that a piece of straight line should be laid between the two curves, on which the super-elevation of one rail may die out and the super-elevation of the other rail may attain its proper amount.

If the piece of straight line cannot be given, the junction of the two curves should be laid with check rails, but the proper plan in all cases where a curve joins a straight line, or where two curves join one another, is to ease off the one curve into the other, or into the straight line by a 'curve of adjustment,' that is to say, by a change of curvature so graduated that the super-elevation of the rails not only varies gradually, but at the same time is also at each point suitable to the curvature.

LECTURE IV.

POINTS AND CROSSINGS—POINT RODS—TRAILING AND FACING POINTS—SINGLE-TONGUE POINTS—MANUFACTURE OF CROSSINGS—SLIP POINTS—CONTRACTORS' POINTS AND CROSSINGS—OUT-DOOR SIGNALS—HAND SIGNALS—SEMAPHORE SIGNALS—AUDIBLE SIGNALS—JUNCTION SIGNALS—SLOTTED SIGNALS—INTERLOCKING POINTS AND SIGNALS—DETAILS OF INTERLOCKING—SPRING CATCH ROD—INTERLOCKING GATES—COMPENSATION FOR TEMPERATURE—SWITCH LOCKING BAR—GENERAL APPLICATION OF INTERLOCKING.

In my last lectures I completed the description of the inert portion of a railway proper. I now come to what may be termed the mechanism of a railway. Of this I will first consider points and crossings which enable vehicles to pass from one line to another.

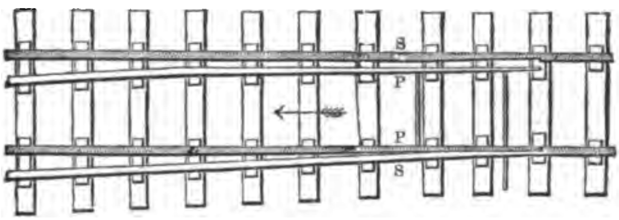


Fig. 60. Plan of a pair of points—the points standing right for the straight line.

Points, which are often called switches, are movable rails pivoted at one end. They are placed at the junction of one line of way with another line of way, as shown in fig. 60, in which the movable point rails are marked with the letter P. These rails, as will be seen, are tapered to allow them to fit closely against the rails which do not

move, which are called the stock rails, and are marked with the letter S.

Fig. 60 shows by the etched or shaded lines the position of the movable points when adjusted for vehicles to run along the straight line, and fig. 61, by the same means, the position of the points when adjusted for vehicles to run along the curved or diverging line.

Point rails are usually about 14 feet long, but where the diverging curve is very sharp, as is often the case in sidings and similar positions, the point rails are made much shorter. The heel or pivot end of the point has to be fully 2 clear inches from the stock rail, in order to let the flanges of the wheels pass freely through, and it therefore follows that at points one of the lines must of necessity diverge rapidly from the other. This rapid divergence is always placed on the least important line of the two, and

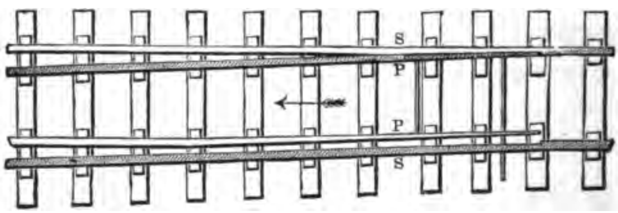


FIG. 61. Plan of a pair of points—the points standing right for the diverging line.

trains running over the points when they are set for the diverging line should go slowly.

On the other hand, when the points are so placed as to cause a train to continue its course along the straight line, there is no necessity for a limitation of speed provided that the points are accurately adjusted and are held fast in their position. It is to be remembered also that owing to the construction of the points, and in consequence of the intersection of the different lines of way, little or no super-elevation can usually be given to the outer rail of the diverging line, and thus there is an

additional reason for a cautious rate of speed in the case of trains travelling on the diverging line. If the points are made shorter than 14 ft., the rate of divergence is of course greatly increased thereby, seeing that the clearance at the heel of the points must always be the same and sufficient to allow the flanges of wheels to pass between the stock rail and the point rail.

Figs. 62 and 63 show what is called a cross-over road, which is a short diagonal line with a pair of points at each end joining two lines of rails together. The cross-over road is shown in two positions; in the first (fig. 62) trains would pass along the two straight lines, and in the second (fig. 63) a train which was being backed

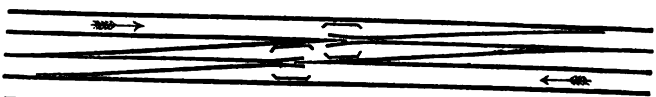


FIG. 62. Plan of a cross-over road—both pairs of points standing right for the straight lines.

on either line would cross over from one straight line to the other straight line, along the diagonal line. The difference between these two sketches, it will be observed,

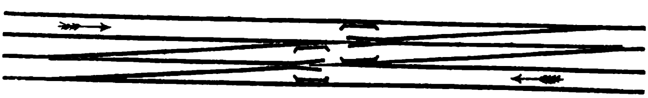


FIG. 63. Plan of a cross-over road—both pairs of points standing right for the diagonal line.

is only that the ends or points of the diagonal line are altered in position.

When a pair of wheels travels on the diagonal line, the flanges of the right-hand wheels will have to cross the rails on the left hand, or near side, of the straight line. This is effected by making a gap in the straight rail at least as deep as the projection of the flange below the tread of the wheel, and to allow wheels on

the straight line similarly to cross the diagonal line, a gap is required to be made in the diagonal line of rails. The intersection of the rails at these gaps constitutes a 'crossing,' and a sketch of one to an enlarged scale is given in fig. 64. In order that the flanges of wheels may pass with accuracy through the gaps, the wheels near the crossing, and the opposite wheels, are guided by what are called wing rails and guard rails. These rails are fixed near to and opposite to the gaps, and, acting as check rails, which I described in my last lecture, prevent the wheels from diverging to the right or left, from striking

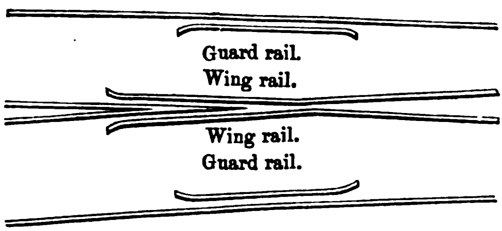


FIG. 64. Plan of a crossing.

against the apex of the crossing, and from passing through the gaps in the wrong direction.

It is obvious that the end of the point and the end of the crossing, being necessarily weakened, in the one case by the small width of the point, and in the other case by the cutting away of the rail to leave the gaps

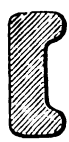
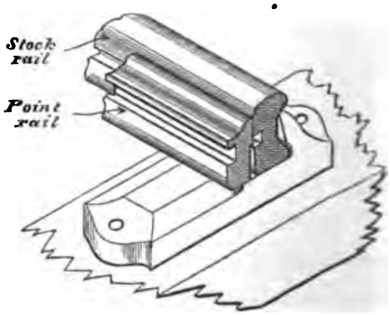


FIG. 65. Filled rail.



Filled stock rail and filled point rail.
FIG. 66.

for the passage of the flanges, must be exposed to high

strains relatively to their dimensions. In this country points and crossings are now usually made of steel rails, and in order to give them additional strength, these rails, including the stock rail, are often made with the space between the flanges filled on one or both sides; these rails are called filled rails, and are shown in figs. 65 and 66. The stock rail is often notched or cranked to receive the end of the point, so that when the point is against the stock rail there may be no projection against which the flange of a passing wheel can strike.

In cases where the stock rail is not a filled rail, but a rail of the ordinary section, the end of the point is often housed in under the flange of the stock rail (fig. 67), the extreme end being kept lower than the top of the stock rail, and below the level at which it could be struck by the flanges of the wheels.

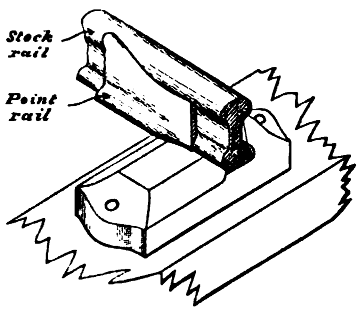


FIG. 67. Point and stock rail. Point housed below flange of stock rail.

In using all descriptions of switches, care is taken that the point rails may be as stiff as possible laterally, and be well and continuously supported laterally against the stock rail; if this be not done, there is a danger of the sideways pressure of the flange of any wheel bending the point rail, and so springing open its extreme and thin end, in which case a succeeding wheel might strike it and mount the rail, or might pass on the wrong side of it.

The pointed end of the switch is so shaped that it may fit accurately against the stock rail, and when the point is moved over to the stock rail, the point rail and the stock rail are in contact for a considerable longitudinal distance

measured along the point rail, indeed until the divergence of the two rails becomes greater than the width of the point rail. Where the point rail and stock rail do not touch each other, short studs projecting from the stock rail, and at a level below where they could be struck by the flange of a wheel, are fixed to the stock rail, to afford a lateral support to the point rail, and prevent it from bending sideways from the pressure of the flanges of the wheels.

Points at their thin end are made to move about 3¾ or 4 in., but it is only absolutely necessary that they should open about 2 in., and the larger space is adopted in order to avoid the possibility of the back of a wheel striking the end of the open point.

If the points are not shut completely one way or the other, but are left half open, the wheels may run on both stock rails, and (technically speaking) 'get astride' on

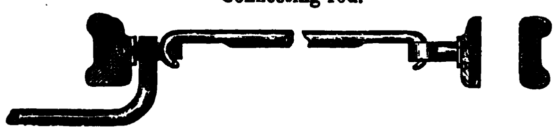


FIG. 68. Cross section of a pair of points and stock rails with connecting rod and point rod.

the points. Both the point rails in such a case would be between the flanges of the wheels, which, travelling on the diverging lines of the two stock rails, would leave the rails as soon as the divergence of the rails was sufficient to allow the wheels to fall between them.

The two tongues of the points have to be rigidly connected, so that they may move accurately together, and that the horizontal distance between them may be properly preserved. The connection is made by cross rods, called connecting rods, shown in fig. 68, which fit

into rings fixed to the points, about 2 ft. apart. It is of great consequence that the connecting rods should by no possibility become loose, or be detached from the points, for if one point be moved without the other, any train passing over the points as facing points must be thrown off the line.

The rod by which motion is imparted is called the point rod; it is made fast to the points and extended horizontally to a safe position, and connected with a lever which is worked by the pointsman. The point rod is now-a-days usually prolonged into the signal-box, from which both points and signals are worked, as will be explained hereafter. Indeed, this arrangement is now required by the Board of Trade to be adopted on all new railways in this country, at least in the case of points connected with lines on which passenger trains travel. On old lines, and in goods yards or sidings, the points are often worked by a lever on the ground close to the points. Such ground levers are either fitted with a ratchet and holding pin, as shown in fig. 69, or are counterweighted, as shown in fig. 70, so that the points must by the action of the weight stand right for one line; when it is desired to set the points for the other line, the lever must be used to raise the weight, which, when the lever is released, puts the points back to their original position.

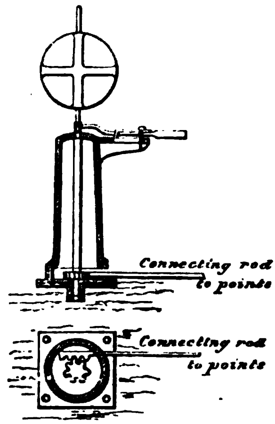


FIG. 69. Vertical pillar with horizontal point lever.

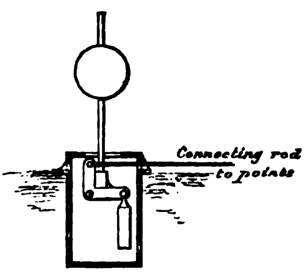


FIG. 70. Counterweighted point lever.

A disc or other signal is often attached to the lever as an indicator, to show which way the points are standing.

In certain cases it is necessary that lines should diverge in two directions from one point, which is accomplished by what are called 'three throw' points (fig. 71), in which there are two sets of tongues working side by

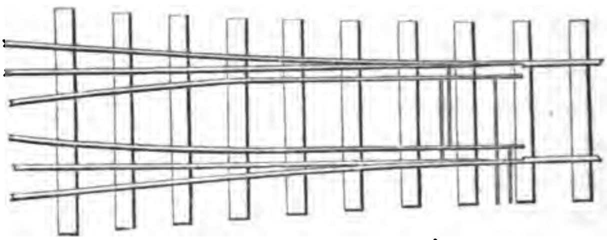


FIG. 71. Plan of three throw points.

side. Three throw points are rather complicated, and involve somewhat more abrupt divergence than ordinary points; many engineers prefer, therefore, an arrangement

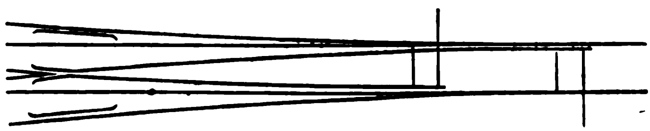


FIG. 72. Arrangement to avoid the use of three throw points.

shown in fig. 71, in which the second pair of points is placed immediately beyond the heel of the first pair of points.

The tongues of switches and the ends of crossings are almost of necessity objectionably weak and rapidly wear out, while in order that the wheels of vehicles may pass over them properly, both points and crossings ought to be always in most accurate adjustment and in perfect repair. Thus the points and crossings are critical parts of the permanent way, and require constant attention and frequent renewal. A large proportion of the mishaps

which occur on railways, due to defects in the permanent way, are in some manner connected with the state of the points and crossings.

When the train approaches a pair of points from their heel or pivot end, they are called '*trailing points*'; but when points are approached by a train so that their thin end and not their heel is first touched, they are called '*facing points.*' The same pair of points are thus called 'trailing' or 'facing' points according to the direction from which they are approached by a train. The construction of both is identical; the difference is the use to which they are put. Trailing points cause a convergence of traffic: facing points cause a divergence of traffic. Any error of working trailing points is not of much consequence, as in that case the flange of the wheel of the first vehicle as it advances from the fixed rail on to the movable rail moves the points into their proper position, if they have not been already so placed, and the succeeding wheels repeat the operation; it is thus obvious that whichever way trailing points stand cannot affect the direction of the train passing over them, if the train can alter the position of the points to suit itself, as in the case of counterweighted points (fig. 70, p. 117), which are consequently often used as '*self-acting points,*' and are not adjusted by a signalman when they are to be used by a train as trailing points. With modern signalling appliances, by which all points and signal rods are concentrated in one apparatus, and are held fast in both positions, the use of self-acting or counterweighted trailing points has to be abandoned.

In the case of facing points any want of accuracy in adjustment is most serious, as by merely moving the points 2 inches one way or the other the direction of a train can be altered, and if of two lines connected by facing points one line be clear and the other line be already occupied

by trucks or carriages standing on it, an approaching train can be directed either to safety or to destruction by this small amount of motion. Further, if the points be not properly adjusted, or be moved during the passage of a train over them, one part of the train may go on one line and one on the other, as indeed happened in the case of the dreadful accident which occurred some years ago at Wigan, and in which many lives were lost. From some of the above causes many serious accidents have occurred at facing points, and every engineer avoids as much as possible inserting them on a main line. They cannot, however, be dispensed with altogether, as it would be impossible to conduct the present traffic of railways without them. But every effort should be made to guard against the dangers involved in the use of facing points, and to a great extent their inherent objections have been overcome by the appliances in connection with modern signalling apparatus.

The greatest care should be taken to keep the gauge of the line at points and crossings accurate, and constant attention is required to this matter on account of the strains to which these parts of a railway are exposed, in consequence of the unavoidable sideways pressure and blows caused by engines and carriages, as they pass over them. In order to avoid as much as possible the sideways motion and consequent blows on the rail, and for the reason referred to in the next paragraph, the gauge of points and crossings is generally kept about a quarter of an inch narrower than other parts of the line, and (as has been stated in a former lecture) the plate-layers are furnished with a gauge for points and crossings shorter than that for the line in general.

If the gauge of the line at facing points be wider than at other parts of the line, the danger of vehicles going on

the wrong line is increased, and for these reasons. The gauge of the throats of even the new wheels of rolling stock is, as explained above (page 66), usually from $\frac{3}{4}$ of an inch to an inch narrower than the proper gauge of the rails, and thus the tongue or thin end of the switch by which the direction of a train is changed, can be misplaced to that extent without encountering the flange of a wheel, supposing the wheels to be bearing away from the tongue and pressing sideways against the opposite rail. If in addition the gauge at the points be $\frac{1}{2}$ inch wider than the ordinary gauge of the line, the tongue of the switch could be further misplaced to that extent in addition to the clearance of the wheel, or to a total amount of $1\frac{1}{4}$ inch, without diverting that pair of wheels from the straight line; if the following pair of wheels, instead of bearing away from the tongue of the switch, bore towards it, the flanges of these wheels might enter into the space of $1\frac{1}{4}$ inch, and be diverted along a different path to that which the former wheels followed, and most disastrous consequences ensue. This is sometimes called 'splitting a train,' and is explained by fig. 73. If, however, the

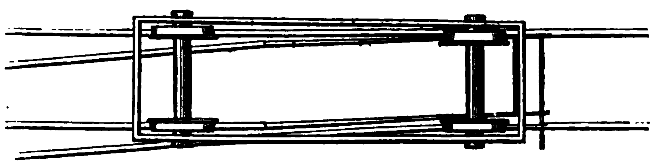


FIG. 73. 'Splitting a train.'

gauge be tight, then even if the points have not been properly adjusted, the flange of the first wheel of a train will probably push the points home against one or other stock rail, the succeeding wheels will keep them there, and the whole train will at least travel on the same line of rails.

To return to the construction of the points; the stock rails and the point rails are supported on chairs of special form shown in figs. 74 and 75. The chairs at the heel of the points, or immediately beyond the heel of the points, are made to hold the two rails, viz. the stock rail and the rail attached to the movable tongue, in one chair (fig. 74), like the chairs for a check rail. The other point chairs (fig. 75) are made so as to afford a smooth surface, which is kept clean and freely lubricated, and on which the tongue slides backwards and forwards.

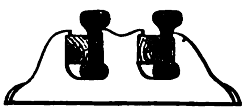


Fig. 74. Heel chair.

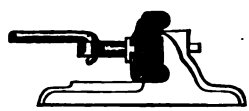


Fig. 75. Sliding chair.

The stock rail is secured to the chair by bolts or studs passing sideways through the stock rail and the jaw of the chair.

Points are sometimes, though rarely, made with a fixed point, and but one movable tongue, as shown in fig. 76, but this, for many reasons, is not a good arrangement. When the tongue is set right for the diverging line, as shown in fig. 76, from there being no opposite tongue

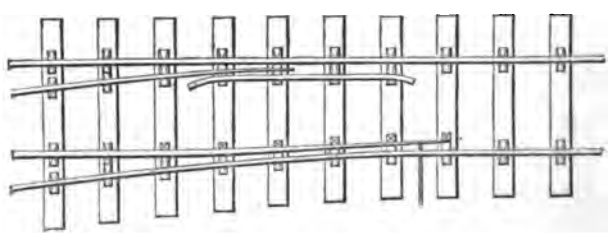


Fig. 76. Single-tongued points.

to direct the wheels along the diverging line of rails, the act of divergence is caused altogether by the backs of the

wheels pressing against the back of the movable tongue, which thus acts not as an ordinary point rail, but as a check rail, for fulfilling which purpose it is, from its shape and thinness, not at all well fitted. The guidance given to the wheels by the back of the tongue to cause them to diverge from the straight line is more abrupt than is the case with double-tongued points, or when with single-tongued points the movable tongue is placed on the outside line of the curve, in which cases guidance is given to the opposite wheels by the inner or proper side of the movable tongue on the outer rail of the curve. The extra abruptness of divergence, when the tongue is on the inner line of the curve, is caused by the shape of the back of the movable tongue, which fits against the stock rail. As the divergence which takes place at even the best double-tongued points is very abrupt, any addition to the abruptness is a serious objection to the use of single-tongued points. On whichever side, however, the movable tongue is placed, there is a further objection to the single-tongued points, from their not affording so much support to the treads of the wheels as the double-tongued points give. It will be seen by fig. 76, in which the point is set right for the diverging line, that the treads of wheels on the outer line of the curve cannot be nearly so well supported, until they run beyond the fixed point, as they would be if a second movable point of the same length as the opposite point were substituted for the fixed point. To get over this difficulty when single points are used, a casting is sometimes placed on the inner side of the rail which is opposite to the single movable tongue at such a level that the flanges of the wheels may run on the casting, and so support the weight, instead of its resting entirely on the outside edges of the treads of the wheels.

The advantages of the single-tongued switches are a small saving in first cost, and perhaps some saving in maintenance, from there being fewer moving parts. The objections to their use, referred to above, overbalance their advantages, and they are but seldom adopted for main lines. They may however be usefully employed in sidings and in unimportant situations and for temporary railways.

Crossings are made either by uniting rails which are generally made of a section rolled for the purpose, such as filled rails (fig. 65), which are supported in special chairs, or they are cast in one piece, long enough and wide enough to insure steadiness on their base, as shown in fig. 77. The grooves shown in the figure in the upper surface of the casting are the passages along which the wheels pass.

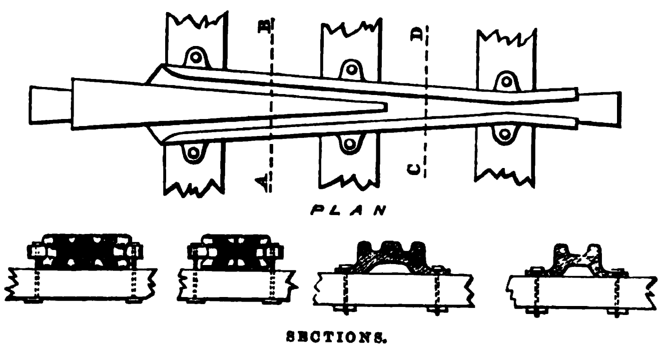


FIG. 77. Cast-steel crossings.

Where it is desired to connect two lines of way which cross each other at an acute angle, it is possible to do so by two pairs of points called slip points (fig. 78), and by a very short line which connects the slip points. On fig. 78 the slip points are shown in the two positions in which they can be placed. The slip points and the connecting

line itself are introduced between the extreme points of intersection of the two crossing lines, and the short connecting line does not itself cross either of the other two lines. Slip points have the advantage that they do not entail any additional crossings, but they can only be introduced where the angle between the two intersecting lines is such that the curve of the connecting line, which

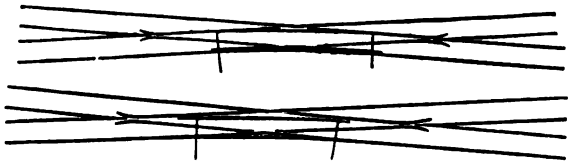


FIG. 78. Single slip points.

is tangential to both crossing and crossed lines at the connecting points, is not unduly sharp. There must be space between the two intersecting lines opposite to the ends of the slip points sufficient to allow the ends of the points to be moved 3½ inches away from their stock rails without interfering with the adjacent line.

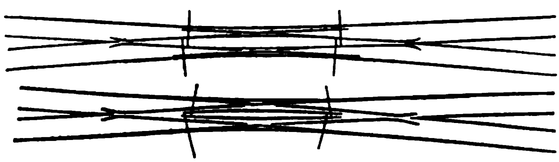


FIG. 79. Double slip points.

Double slip points (fig. 79), which also are shown in two positions, are of the same description, and serve to connect the two intersecting lines in both directions.

Safety or catch points (fig. 80) are points leading out of a siding and with either no rails or else with only one or two lengths of rails joined to the heel of the points. Their purpose is to prevent a train or single vehicles from leaving the siding without the overt act of some one in charge

moving the points. Safety points are weighted or locked so that they stand normally in the opposite position to that which they would occupy if a train were being directed from the siding to the main line. Thus, if a truck should be blown along the siding by the wind, or if an engine-driver should start his train without orders, or if anything is being shunted on the siding without permission of the signalman in charge of the main line, and without his setting the points right for vehicles leaving

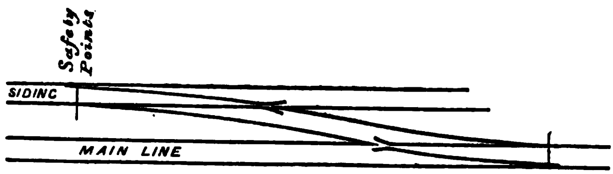


FIG. 80. Safety points.

the siding and going on to the main line, the vehicles run over the end of the dummy rails, and imbed themselves harmlessly in the ballast, but do not run on to and foul the main line. Sometimes safety points are joined on to a short subsidiary siding terminating with buffer stops or in a heap of earth, so that vehicles may be brought up against that obstacle instead of running off the line into the ballast.

The present form of points and crossings was not adopted till long after the introduction of railways. The

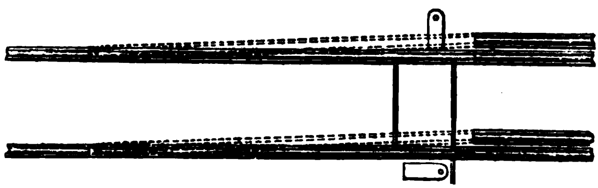


FIG. 81. Contractors' points.

original mode of providing for trains crossing from one line to another was what may now be seen on most tem-

porary railways, such as those used by contractors. In this method (fig. 81) the four ordinary rails of the two diverging lines are brought as close together as the space necessary for the flanges of the wheels will allow, and the two rails of the single line from which divergence is to be given, which are rails of the ordinary description, and not thin specially shaped point rails, are pivoted, so that their free ends can be placed opposite the ends of either pair of the diverging lines. The exact amount of movement is regulated by a lever, and the movable rails are kept fast by pins dropping into holes in the rails and sleepers, or by a hinged catch on the sleepers.

In the case of the old form of crossings (fig. 82) which are still used on temporary railways, the rails are not cut for the flanges to pass, but one rail is elevated sufficiently above the other to allow it to cross over the top of the lower rail. The higher rail is pivoted so that it can be moved out of the way when traffic has to pass along the lower rail. This description of crossing has the disadvantage of requiring to be moved every time a train passes along the lower rail, and it cannot compare in convenience with the present system, nor is it adapted to the complications of many lines intersecting one another. The old-fashioned points and crossings are extremely handy for temporary railways, and possess an undoubted advantage as compared with the thin tongues of the points and crossings now in use, in that the rails are unweakened. The objection to the old form of points lies in the necessity they entail of a break of continuity between the ends of the movable and fixed rails;

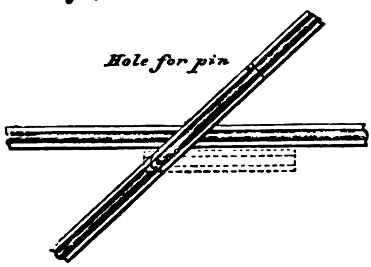


FIG. 82. Contractors' crossing.

but if this objection could be removed by the joint being properly secured and made as strong as other joints on the line, this description of points would be superior to the modern form, especially in the case of those facing points over which trains have to travel at high velocities.

There are, as you no doubt know, other well-known means other than points and crossings for transferring vehicles from one line of rails to another. I allude to the turntables and traversers which are so often seen at large stations. But I am sorry to say that I cannot find time in this course of lectures to describe either the general arrangements or any of the details of stations, and I must therefore proceed at once to the subject of signals.

In the first instance I will deal with the 'out door' signals, namely, those exhibited to the engine-drivers and guards. There are in addition signals used for conveying instructions between different signalmen, which are now-a-days generally worked by electricity, and these will be referred to in a subsequent lecture.

The 'out door' signals given are always two and often three in number. The two signals which are always employed are 'All right,' or 'Proceed,' and 'Danger,' or 'Stop'; a third and intermediate signal is sometimes given to signify caution or 'Proceed slowly.' The mode originally adopted, and indeed still in use on many lines, for signalling trains is that signalling stations having been erected at suitable places, no train is allowed to pass any signalling station until the previous train has passed a definite time, say ten minutes, during which time the 'Danger' signal is exhibited. When a train has left ten minutes previously, the 'Caution' signal is exhibited, and this indicates to the driver of any following train that a train has passed but from ten to fifteen minutes previously,

and that it behoves him therefore to proceed cautiously. The 'Caution' signal is continued for perhaps another five minutes, and then the 'All right' signal is given, which therefore tells an engine-driver that the previous train has passed at least fifteen minutes previously before he came to the signals. The intervals of time vary in different places with the exigencies or peculiarities of the traffic.

The third signal is being now to a great extent discarded. It was useful so long as efficient signalling inferred the preservation of an interval of time between trains as they passed any given place; but since the employment of the electric telegraph in working railways, the object aimed at in signalling is to preserve not an interval of time, but an interval of space, between trains. So long as the latter is preserved, no collision can take place, but the attempt to maintain an interval of time between trains is illusory. Between one signalling station and another an engine may break down, or the train may be in many ways prevented from running accurately to time; and thus, though all the time signals may have been correctly exhibited and a proper interval of time may have been observed at a signalling station between any train and the train following it, yet before the first train reaches the succeeding signalling station the second train may have caught up the first and have run into it.

With the present system of communication by telegraph between signalmen, each line of rails of a railway is divided into telegraphic districts, and it is a rule that no two trains shall be on one district or division of the same line of rails at one time. The system by which this is carried out is called the 'Block System,' and will be referred to in detail in a subsequent lecture; but in connection with it only two signals need be given to an engine-

driver, that is, 'All right, Go on,' for the line is clear as far as the next station ; or 'Danger, Stop,' because a train is already in possession of the particular division on which your train is about to enter.

In this way the fact that trains travel at various speeds becomes of little consequence, and the simple question to be signalled is whether a particular division of the line is occupied or unoccupied when a train desires to enter on that division.

Hand signals, which are much used in shunting, are given in daylight by flags, or by a man holding up his arms, and at night by hand lamps. The 'All right' signal is given in daylight by a white flag or by holding the arm horizontally, as in fig. 83, and at night by showing a

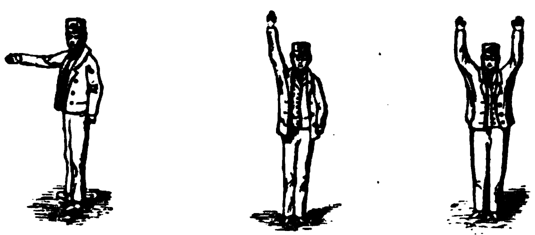


FIG. 83. 'All right' or 'go on.' FIG. 84. 'Caution.' FIG. 85. 'Danger' or 'stop.'
Hand signals.

steady white light from a hand lamp. The 'Caution' signal is given in daylight by a green flag, or by holding one arm straight up, as in fig. 84, and at night by a green light. The 'Danger' or 'Stop' signal is given in daylight by a red flag, or by holding up both arms vertically, as in fig. 85, or by waving a cap, flag, or other object violently. At night the 'Danger' signal is given by a red light, or (in the absence of a red light) by waving violently any other light across the line.

The type of fixed signals originally used on the various railways in England differed according to the ideas of

each engineer, and to such an extent that in some cases a signal which indicated 'All right' on one railway denoted 'Danger' on other railways. The sketches figs. 86 to 89 show a few of the different signals originally used on well-known railways, and some of them are still at work.

The signal known as the Semaphore signal (fig. 90), introduced on railways about 1841 by Mr. C. H. Gregory, has, however, been found so superior to all the other types, that it is rapidly superseding all the other signals, and before long it will probably be the only daylight fixed signal used in this country.

The semaphore signal, as applied to railway traffic,

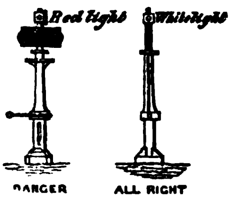


FIG. 86. Liverpool and Manchester Railway signals.

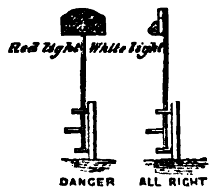


FIG. 87. Grand Junction Railway signals.

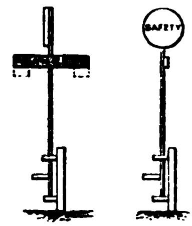


FIG. 88. Great Western Railway signals.

consists of a vertical post, which has one or more movable boards, or arms, pivoted to it at their upper ends, and these arms are capable of being moved through a right angle. If the three signals of 'All right,' 'Caution,' and 'Danger' are in use, the semaphore signal exhibits them in the following way: when the board is hanging vertically (as shown by dotted lines in fig. 90), and is concealed by the post, the signal denotes 'All right!' when it is inclined at an angle of 45 degrees (as shown on the right hand side of the fig.), it denotes 'Caution!' and when it is raised to the horizontal position (as shown on the left hand side of the fig.), it means 'Stop!' At night a lamp is used, with coloured glasses worked by the same rod

which works the semaphore arms; when three signals are in use the white light means 'All right!' the green light 'Caution!' and the red light 'Stop!'

The semaphore signal post often has arms on both sides of it, and occasionally, at stations or junctions, two or more tiers of arms, one above another; but in all cases the arms on one side refer to trains proceeding in one direction, and the arms on the other side to trains proceeding in the other direction. The driver of any train approaching the signal post has to consider only the arms on the left hand, or 'near' side, of the post. The arms

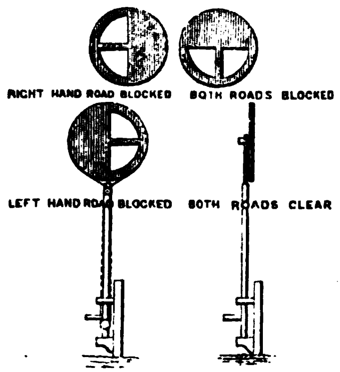


FIG. 89. London and South-Western Railway signals.

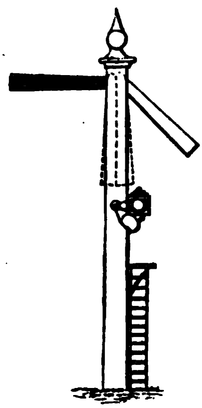


FIG. 90. Semaph. re signal.

are painted red on the side which faces the approaching train to which they refer. The other side of the arm is generally painted white, so as to be comparatively invisible.

The caution signal above mentioned is, as has been said, being gradually discarded, and only two signals used; that is to say, the arm at 45 degrees and the green light are now in many cases taken to mean 'All right!' and the horizontal position of the arm and the red light

mean 'Stop!' The block system having rendered a third or cautionary signal unnecessary, it is an advantage not to have to use a white light for signalling 'All right!' in or near towns, where such a light may be confused with ordinary white lights. In other positions a white light has the advantage of being much more visible than a green light, and this is of consequence when trains are travelling at high speeds, and when the light should be seen from a long distance. The vertical position of the semaphore arm, which was the original 'All right!' signal, can scarcely be considered a signal, but rather the absence of one. It is always desirable that an engine-driver should have a distinct affirmative intimation before he proceeds, and with the semaphore arm at an angle of 45 degrees, and with the use of the green light, this object is obtained. Where, then, only two signals are required, viz. 'All right!' and 'Danger!' the latter is always given by the horizontal position of the semaphore arm and by the red light, while the former is generally, and certainly best, given in daylight by the semaphore arm inclined at an angle of 45 degrees, and at night either by the green light or by the white light, according to the particular situation of the signals.

In all cases signals should be counterweighted, so that their tendency is to assume the position indicating 'Danger!' Thus, if a wire or rod breaks, the signal at once flies to 'Danger' and stops all traffic, and the worst that can happen is delay. If the signals were not counterweighted, the weight of the semaphore arm itself might make it assume the position of 'All right!' if the wire or rod were broken, and such a signal might produce a collision or some other disaster.

The main signals of any signalling station are generally placed over or very near to the signal box or cabin in

which the signalman is stationed, but there are auxiliary signals worked from the cabin in either direction. In consequence of the speed at which trains travel, it is necessary to let engine-drivers know how the 'home' signals (as the signals on the signal boxes are generally called) stand before they sight those signals, so that they may have time to slacken speed, and, if necessary, come to a standstill at the 'home' signals. This duty is performed by what are termed 'Distant' and 'Auxiliary' signals, which are placed from a quarter to a half mile away from the 'home' signals, and are worked by wires connected with the levers in the signal box.

Distant signals should, when possible, be so placed that they can be seen from the 'home' signal box, in order that the signalman may see that the signal has obeyed the movement of the lever in the signal box by which he works it. This is necessary, because, when the wires are very long, the contraction and expansion or the stretching of the wires become of importance, and a signalman may think he has properly adjusted the distant signal when he has only taken up the slack of the signal wire. When the signal is in view of the signalman he can of course see by day in clear weather how it stands; and, to give him the same information by night, the distant signal lamps have at their backs small lenses facing towards the main signal box, and called 'back lights,' and movable coloured glasses connected with the wires which move with the main signals.

In positions where the distant signal cannot be seen from the main signal box, mechanical or electrical 'Repeaters' are used for the purpose of showing the signalman how his distant signal stands. The mechanical repeater acts by a return and independent wire connected to the semaphore arm, so that the movement of the arm either

moves another arm within sight of the signalman, or moves an indicator, such as a disc or small semaphore, in the signalman's cabin.

The alteration in the length of the repeating wire from temperature or other causes is an objection to the mechanical repeater, and constant attention to the condition of the wire is required.

This objection does not attach to the electrical repeater (fig. 91), which is generally a miniature semaphore or disc placed in the signalman's cabin, and worked by an electro-magnet. The magnet is connected by a wire to the distant signal, and works by contact being made or broken at the distant signal, so that the movement of the distant signal is repeated in miniature on the small signal in the signal box. Electricity has also been employed to show a signalman whether the lamp of his distant signal is or is not alight, which is a matter of great importance where the distant signal cannot be seen from the signal box. The temperature of the lamp maintains the contact of two wires connected with an electro-magnet; if the lamp goes out and the temperature falls, contact is broken, and notice is given to the signalman by a small alarm bell being rung and by the word 'In' shown on the miniature signal changing to the word 'Out.'

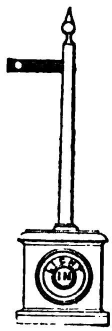


FIG. 91. Electric repeater.

Special and audible signals are used in fogs to supplement the visible signals. The ordinary well-known fog signal (fig. 92) is made of detonating composition, inclosed in a flattish metal capsule. The capsule is furnished with two thin metal clips, which can be bent round the rail so as to prevent the capsule from slipping off accidentally, and the pressure of a wheel causes the

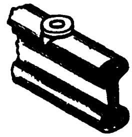


FIG. 92. Fog signal.

detonating composition to explode. In foggy weather a platelayer or some other person is stationed at the foot of the signal posts and at other convenient positions, and his duty is to place and keep one or two detonating signals on the rails whenever the semaphore arm is at 'Danger!' removing the detonators when the arm is at 'All right!' or 'Caution!' The detonating signals are used largely under other circumstances, as (for example) in the case of a train breaking down, or during repairs to the permanent way, and all guards and engine-drivers are supplied with detonating signals for use in emergencies. They are a most valuable addition to visible signals; for a man can shut his eyes, but he cannot shut his ears. The only danger connected with detonating or other audible signals lies in the possible failure of the detonating powder or other means employed for making a noise. With proper care, however, the risk of failure is small, and in all cases detonating signals should be used in duplicate.

Means are sometimes adopted, although very rarely, of placing detonating signals on the rails by a lever connected to the semaphore arm, so that when the semaphore arm is put at 'Danger' the lever may place a detonator on the rails, and when the semaphore arm is put to 'Caution' the detonator may be withdrawn.

Mechanical means for giving audible signals have been proposed, and may be said to be on their trial. The best known are those which act on the whistle of the locomotive or strike a gong on the locomotive, or in the guard's van. The method of their application is more or less as follows (see fig. 93): at the place at which it is desired to give an audible signal to those in charge of the train, a rigid or elastic inclined plane is placed so that a pendent rod connected with the steam whistle or gong may be raised by it as the engine or van passes. The raising of

the pendent rod opens the whistle or causes a weighted hammer to strike a gong, and thus attracts the attention of the engine-driver or guard. The inclined plane is made movable, so that when the semaphore arm is at 'All right' the inclined plane is altogether removed, but when the semaphore is at 'Danger' the inclined plane is placed so as to engage with the end of the pendent rod. The same object has been attained by means of electricity, the making and breaking of contact being caused by much the same means as above described. It is quite possible that a system of this sort may be found valuable as an adjunct to visible signals, but it is not probable that it will replace them, as the visible signals are simpler, less

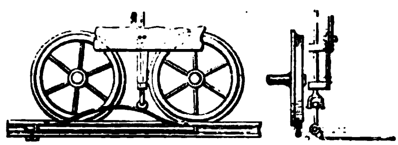
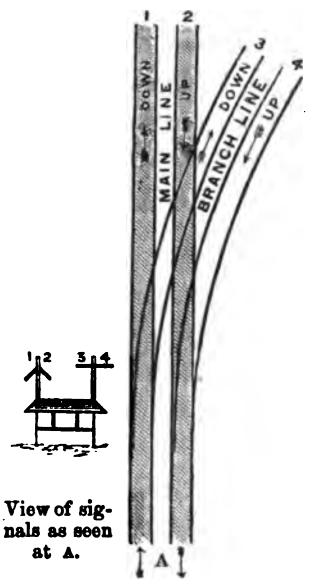


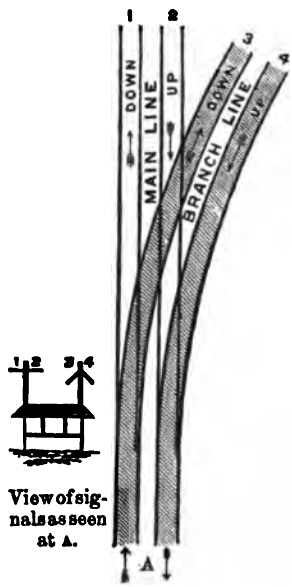
FIG. 93. Fixed audible signal.

liable to derangement, and, except in thick weather, more efficient than audible signals.

The principle of the interlocking of points and signals has now to be considered. In passing from one line of rails to another trains 'foul' (as it is technically called) all the lines which they cross, including the line from which they start, and the line on which they eventually arrive. During this time all other traffic on these lines must be stopped. In figs. 94 and 95, three diagram plans are given of an ordinary junction with a double main line of rails, and a double branch line, together with the signals referring thereto. The signals on the left hand post refer to the main line, and those on the right hand post refer to the branch line. The numbers 1, 2, 3, 4, on the signals show the lines to which each arm refers. In addition,

there would be distant signals about half a mile away, and worked by wires from the signal box, but these are not shown on the diagrams, nor shall I refer to them, as they follow the movements of the main signals. If the points are set open for both the main lines (fig. 94), or if the points are set open for both the branch lines (fig. 95), the trains would in each case travel safely. In the





Diagrams of junctions.

FIG. 94. Points and signals right for up and down main lines.

FIG. 95. Points and signals right for up and down branch lines.

diagrams the paths along which trains can travel safely at the same moment and in accordance with the signals exhibited above the signal box are shown by the shaded lines. It is obvious that so long as a train is passing from the main down line to the branch down line, all traffic, excepting upon the branch up line, which is parallel to the branch down line, must be stopped, because any train

travelling on the main up line might cut the branch down train in two as it crossed over the main up line. It would, however, be quite safe for a main down train and an up branch train to pass at one time, and the arrangement of the signals and points to effect this is shown in fig. 96. The three diagrams (figs. 94, 95, 96) show the only safe combinations of two trains passing the signals at one time.

Assuming that at an ordinary junction of two branch lines joining two main lines there are two point levers and four signal levers (neglecting for the moment the distant signal levers), there would be of the above six levers 64 possible combinations. The signals might be arranged in any of the 16 ways shown in fig. 97, and the points might occupy any of four positions irrespective of the position of the signals. Of the 64 combinations thus possible only 13 are safe, and the rest would be such as might lure an engine-driver into danger.

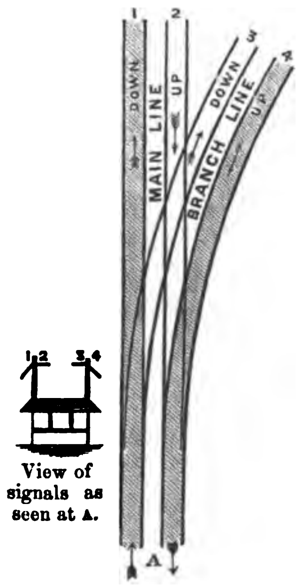


FIG. 96. Diagram of junction. Points and signals right for main down and branch up lines.

Formerly a signalman at such a junction could, as was his duty,

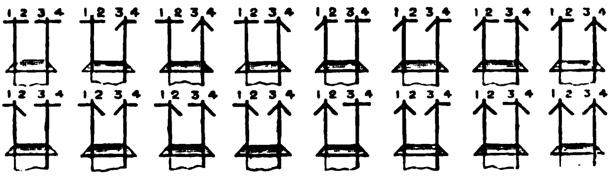


FIG. 97. Combinations of signals at an ordinary double junction.

adjust the points first, and then lower the signal to allow

an engine-driver to pass; but he might lower the signals without adjusting the points, and there was no mechanical contrivance to insure the signalman's giving all signals in accordance with the position of the points. It was consequently quite possible in that state of things, and it occasionally happened, that the signalman would give a signal for the branch down train and the main up train to come up at the same time, and so cause a collision. It was to counteract these dangers that interlocking signals, which I will endeavour now to describe, were introduced.

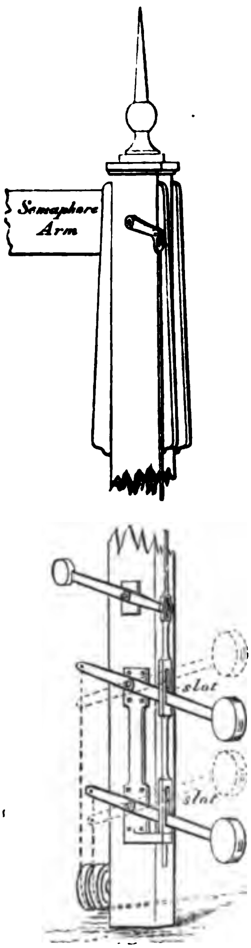


Fig. 98.
Slotted signal rod.

I will begin with a very simple example of the principle.

In certain cases it has been found desirable that two signalmen should control one signal, so that the consent of both men should be necessary to allow a train to pass the signal. This is effected in a simple way by having slots (shown in fig. 98) in the rod which works the signal. In each of these slots a pivoted lever can be moved up and down, and one lever is worked by one signalman and the other lever by the other signalman. Supposing that each lever is at the lower end of its slot, and that either lever in that position retains the semaphore arm at 'Danger,' then if one signalman moves his lever, the other lever will still uphold the

semaphore arm, and consequently the first signalman's lever will be inoperative so far as giving a signal is concerned. When, however, the second signalman moves his lever, the remaining obstacle to the movement of the semaphore arm is withdrawn and the signal falls by gravity, in agreement with the concordant intentions of the two men.

This principle of slotting the signal or point rod is capable of almost unlimited extension, and any number of slots, in each of which a pivoted lever or a pin may work, may be placed in any suitable position in the system of rods. As the different pins can be worked by different handles, signals may thus be so arranged that the consentaneous action of certain signalmen will be required, or one man may have to move any specified number of handles before a signal can be given for a train to pass.

The system of controlling the motion of the rods by pins working in slots was the germ of the system introduced by Mr. Saxby in 1856 in his invention of combined interlocking signals, by which the points and signals of any junction, however complicated, were connected together in such a way that it was mechanically impossible that the position of the points should be at any time contradictory to the position of the signals, or that incompatible signals should be given.

When the principle is extended from an ordinary junction to a complicated station yard or to a junction with many intersecting lines, the problem becomes more intricate, but the system itself is capable of indefinite extension, to suit any system of railway working. When there is a complication of lines, the value of the invention is the greater because of the greater liability in such a position to mistakes of various kinds. At Cannon Street

Station, for example, where there are nearly seventy point and signal levers concentrated in one signal box, the number of combinations which would be possible if all the signal and point levers were not interlocked can be expressed only by millions. Of these combinations only 808 are safe, and by the interlocking apparatus these 808 combinations are rendered possible, and all the others impossible.

If a man were to go blindfold into a signal box with an interlocking apparatus, he might, so far as accordance between points and signals is concerned, be allowed with safety to pull over any lever at random. He might doubtless delay the traffic, because he might not know which signal to lower for a particular train, but he could not lower such a signal or produce such a combination of position of points and signals as would, if the signals were obeyed, produce a collision. The results of the interlocking principle may be illustrated by the example of a piano or organ, constructed in such a way that no notes could be played on it which were not in harmony with each other.

Since 1856, up to the present time, various improvements have taken place in this system, which now is known as the Interlocking System. Various inventors have introduced different modes of carrying out the same fundamental principles, viz. that in no case should it be possible, through inadvertence, or carelessness, or misconduct, for a signalman to give conflicting or dangerous signals. The first invention—though it went to the root of the interlocking principle, and indeed effected the immense improvement that conflicting signals could not be given, and that the signals could never be contradictory to the position of the points—was much improved by Mr. Chambers and Mr. Saxby in 1860. The apparatus,

as thus improved in 1860, will serve to exemplify the principles of interlocking, and will first be described.

All the levers required to work the points and signals of any particular junction or station are concentrated side by side in a cast-iron frame, and the points and the signals are connected with the levers by long rods or wires.

A point or signal lever (fig. 99) is generally a bent lever and is pivoted on the bottom plate of the frame. To the short end of the lever, a rod or wire is attached, which is connected with the point or the signal, and as the lever is worked backwards and forwards, the points are moved from one position to another; or, in the case of a signal lever, the signal is raised or lowered. Above the top plate of the frame there are a pair of segmental guiding plates, between which the lever slides. This pair of segmental plates is technically called the 'quadrant,' and in it are cut notches at a proper distance from each other, corresponding with the distance through which the lever should be moved, for the purpose of working the points or signals properly. Into these notches fits a sliding bolt, similar to the catch which may be seen on the reversing lever of a locomotive engine, which is moved up and down in a vertical direction against the front of the

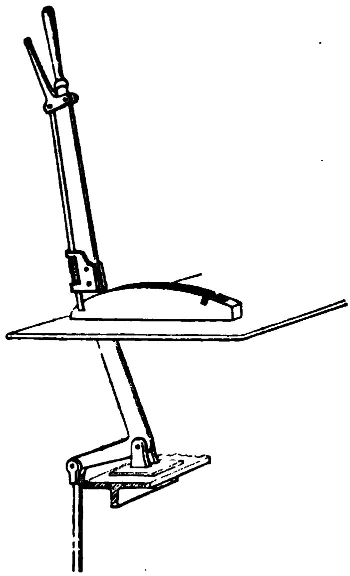


FIG. 99. Point or signal lever in frame

lever as the handle at its upper extremity is grasped or released by the hand of the signalman. When the sliding bolt is in either of the notches, the movement of the lever is complete, and so long as the sliding bolt is in the notch the lever cannot be moved. Thus, before any motion can be given to a lever, the handle of the sliding bolt—or, as it is more generally called, the spring catch-rod—must be grasped by the signalman's hand so as to lift the lower end of it out of the notch in the quadrant; and when the movement of the lever is complete, the spring catch rod drops, or rather is forced by the spring, into the notch at the other end of the quadrant.

I draw attention to the sliding bolt, or spring catch rod, because, as will hereafter be seen, it fulfils very important functions in the most recent improvements of interlocking apparatus.

I shall first refer to the more primitive form of interlocking apparatus, shown in fig. 100. The point or signal levers, 1, 2, 3, as they are moved backwards or forwards, impart a horizontal movement at right angles to the motion of the lever, to one or more long bars, X, Y, Z, which extend from end to end of the apparatus. These bars, which may be of any length, are called locking bars, and move what are called locks. The locks, C, D, E, F, are bars or plates of iron, which have inclined sides, and some of them have notches and projections. One end of each lock is carried by one of the locking bars, and the other end is pivoted at the side of the apparatus opposite to the locking bar on a long fixed pin extending from the top plate to the bottom plate of the frame. When the locking bar is moved by the lever, the notches or projections of the locks are brought before, behind, or are moved away from other levers, and so hold fast or release those other levers as may be required.

The modes by which motion is given by the lever to the locking bars vary in different apparatus. The functions of the locking bar in the apparatus now referred to, and shown generally in fig. 100, will be better understood from the plans (figs. 103, 104, 105), to which I shall refer immediately. In the arrangement under consideration the lever pushes against an inclined or a wedge-shaped plate, and so the locking bars slide at right angles to the

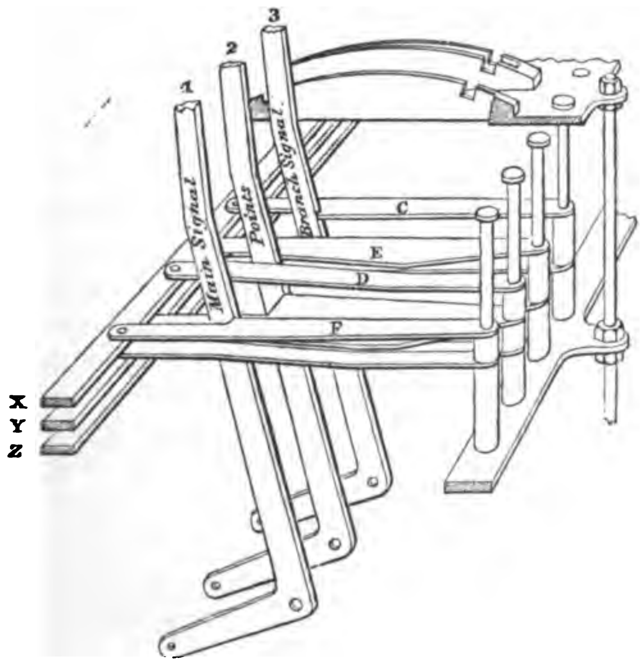


Fig. 100. Combination of point and signal levers.

direction of the path of the lever; in other apparatus the locking bar is moved by rocking shafts, and many other means might be and have been devised for imparting motion to the locking bars through the ageney of the point or signal lever.

The sketch (fig. 101) shows in plan the top plate of

an apparatus with three levers 1, 2, 3. This is the smallest number of levers which will effectually exhibit the action of the interlocking gear, but the principle embodied in the interlocking of three levers can be indefinitely extended to any number of levers by multiplying the parts of the apparatus. In the three-lever apparatus (now under consideration) it will be assumed that the middle lever (2) works the points, and the other two levers (1 and 3) work signals; one signal lever (1) working the signal for the main line, and the other signal lever (3) the signal for a branch line diverging from the main line. The plan of a junction worked by such an apparatus is shown in fig. 102. In the description which I am about to give it must be assumed that when the point lever stands to the front of the frame, the points will be right for the main line, and when the two signal levers are standing to the front, both the signals will be at 'Danger!' When either signal

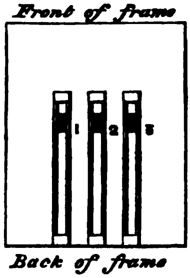


FIG. 101.
Plan of top plate of a three-lever apparatus.

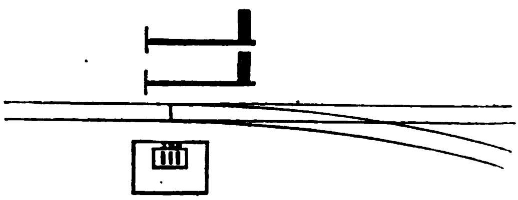


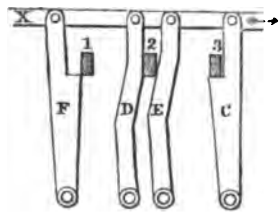
FIG. 102. Plan of a single junction worked by a three-lever apparatus.

lever is at the back of the frame, the signal worked by that lever will be at 'All right!'

In an apparatus of three levers there would be three horizontal locking bars one above the other, and each bar would carry its own locks; and the three plans (figs.

103, 104, and 105), which are taken at different levels, show each of the three horizontal locking bars, with its accompanying locks. When both signals are at 'Danger!' and when, consequently, no trains should pass along either line, the points should be capable of being moved either way. This is required in order to allow of shunting being possible under the protection of the signals, and for other reasons. By inspection of the plans (figs. 103, 104, and 105), it will be seen that when the signal levers are in the positions shown thereon, and when consequently both the signals are at 'Danger,' no obstacle in any of the plans exists to the point lever (No. 2) being moved backwards and forwards. In fig. 103 it will be seen that lever No. 3, which works the branch line signal, cannot be moved, because there is a projection of a bar, or lock, C, interposed behind that lever. When the points stand right for the main line, the lever No. 2 being to the front of the frame, the main line signal ought to be capable of being lowered, and on inspection of the three plans it will be seen that in none of them does any obstacle exist to lever No. 1, which is the main line signal lever, being moved to the back of the frame, and the 'All right' signal given; but it will be seen that

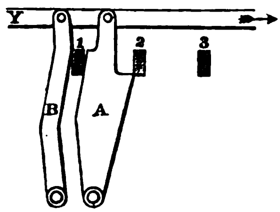
Front of frame.



Back of frame.

FIG. 103. Interlocking gear.

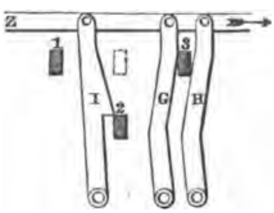
Front of frame.



Back of frame.

FIG. 104. Interlocking gear.

Front of frame.



Back of frame.

FIG. 105. Interlocking gear.

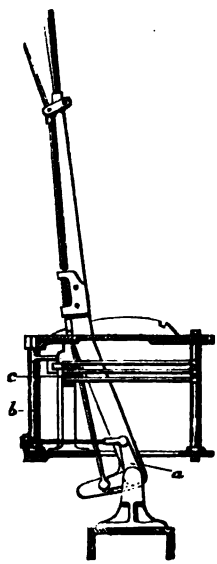
in moving this lever backwards it will slide against an inclined edge of a lock, A (see fig. 104), one end of which is pivoted to the back of the frame, while the other end is attached to the locking bar Y at the front of the frame, and will thus push the locking bar Y from left to right. Opposite to lever No. 2 (the point lever) the lock A has a recess cut in it, forming a shoulder; and by the movement of lever No. 1, causing the locking bar Y to slide, this shoulder will be moved behind the point lever No. 2, and will prevent any movement of that lever. Thus the combination is effected that the signal cannot be given for a train to pass along the main line, unless the point lever is in the proper position for the main line; and that giving the signal renders the point lever incapable of movement. If the main line signal be now put back again to 'Danger!' by moving the lever No. 1 to the front of the frame, it will be seen that the movement of lever No. 1 against the inclined edge of the lock B will move the locking bar Y from right to left, and put things again in the original position, with all the levers standing to the front of the frame. Suppose now that it is necessary that a train should pass from the main to the branch line, and that consequently it is desired to lower the branch signal to 'All right!' It is seen (fig. 103) that when all the levers are to the front of the frame the branch signal lever No. 3 is prevented from being moved by the projection of the lock C. To withdraw this projection the locking bar X must be moved sideways from left to right. In order to set the points right for the branch line, the point lever No. 2 has to be moved from the front to the back of the frame. In doing this the lever No. 2 will press against the inclined face of a lock E (shown in fig. 103), and in doing so will cause the locking bar X to move from right to left; when the movement of lever No. 2 is completed, the whole of the projection of the

lock C will be removed from the path of lever No. 3, which can then be moved to the back of the frame, and the branch signal can be given. The same locking bar X has attached to it, opposite to lever No. 2, a lock F with a shoulder, which, through the motion of the bar X, which unlocks No. 3 lever, will lock No. 1 lever. Thus this combination is effected, that the act of setting the points right for the branch line will unlock the branch line signal, and lock the main line signal. Lastly, it will be seen by fig. 105 that if the branch line signal lever No. 3 be brought to the back of the frame, it will move the locking bar Z from left to right, and bring a projection on the lock I in front of the lever No. 2 when this lever is in its back position. Thus the movement of the lever No. 3 to the back of the frame giving the 'All right!' signal for the branch line, locks the point lever No. 2, which will be then in its back position in the frame (the points having been set for the branch line), just as in a similar way the movement of the signal lever No. 1 to the back of the frame giving the 'All right!' signal for the main line, locked, as we have seen above in fig. 104, the point lever in its forward position with the points standing right for the main line.

This form of apparatus was no doubt a great improvement on all that had gone before; and so long as the moving parts were not much worn, it worked well. It was, however, found that from wear and tear—and an interlocking apparatus at a busy station is never idle—the inclined sides of the locks, or the pins of the levers or cranks, became worn, so that the locks were not always accurately moved into their true positions, and consequently that they did not always hold the levers fast, as they were intended to do. Moreover—and this was a greater defect—from the locks being placed opposite the levers at but a small distance above their fulcrum, the

strain produced against the lock, if the signalman tried to move a locked lever, was very great, and threw too great a stress on the apparatus.

This difficulty is got over in the more modern apparatus by further utilising the spring catch-rod, alluded to above, which, fitting into notches in the quadrant, determines the beginning and the end of each stroke of the lever. If the movement of a lever in working a locking bar be made to hold fast or release the spring catch-rods of other levers, instead of the levers themselves, the straining of the apparatus which had been found so detrimental is avoided; because as it is impossible to move a lever until the spring catch-rod has been raised out of the quadrant, the signalman, if the spring catch-rod be held fast, cannot even commence the movement of a lever which ought not to be moved. Thus the strains due to the long leverage of the point and signal levers are not brought against the locks, and the whole of the interlocking gear can be made much lighter, and can be worked with less friction.



A further improvement is that the upward and downward motion of the spring catch-rod is made the means of actuating the locking bar, irrespective of the movement of the main levers. One of the modes of carrying out this idea is shown in fig. 106. As the spring catch-rod of any lever is grasped by the signalman's hand, and is raised out of the notch in the quadrant, or as it is released and is forced downwards by the spring into the notch, a movement is given to the

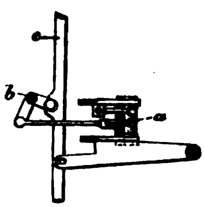


FIG. 106.

locking bar, *c*, by means of the bell crank, *a*, turning the spindle, *b*; and all the necessary locking and unlocking is thus performed independently of the movement of the lever itself. In this way the spring catch-rod becomes not only the recipient of the locking, but also the actuator of the locking, and as a consequence it may be said that the intention of the signalman to move any lever, expressed by his grasping the lever and so raising the spring catch-rod, independently of his putting his intention in force, actuates all the necessary locking.

The locking bar in some form or other is common to all the systems of interlocking, and the difference between the old and new apparatus is in the mode in which motion is imparted to the locking bar, and the mode in which the locking bar controls the levers.

Fig. 107 shows a locking apparatus of the most modern description actuated exclusively by the spring catch-rod. The movement of the spring catch-rod actuates the locking, and consequently the locks are put on or taken off at each end of the stroke of the lever, that is to say, when the spring catch is raised out of, or allowed to fall into, the notch in the quadrant. The principal novelty in the mechanism is the rocker, D, which is a 'slot link' or segmental plate with a curved slot in it.

The object of the introduction of the rocker is this: we require that the act of lifting the catch rod out of its notch prior to moving the lever shall actuate all the proper locking movements, which in the more primitive apparatus were actuated by the movement of the lever itself. But we also require when the lever is moved that both while it is being moved and after it has been pulled over, and after the catch-rod has been dropped into the notch at the other end of the quadrant, all the proper locking shall be maintained. Now if the locking be actuated directly and exclusively by the raising of

the catch-rod, it is clear that dropping the rod into the notch at one end of the quadrant would undo the locking that had been effected by raising the catch-rod at the other end. This difficulty is got over by making the catch-rod actuate the locking indirectly by means of the rocker which is a pivoted lever. The mode by which this is carried out is as follows: a block on the end of the catch-rod, which is raised and lowered as the catch-rod is raised and lowered, runs in a groove in the rocker, and the rocker being pivoted in the middle of its length, the tilting movement given to the rocker by raising the catch-rod is not undone, but is sustained and added to by the travel of the block in the radial slot, and by the act of dropping the catch-rod at the other end of the stroke. In fact the catch-rod actuates the locking mechanism, as I have said, through the intervention of a pivoted lever, and between the raising of the catch-rod and its being lowered, its point of attachment to the lever has been shifted to the other side of the fulcrum of the pivoted lever. Thus, though the movement of the catch-rod has been reversed, the lever is moved in the same direction.

The mode in which the locking is effected in this apparatus, though similar in principle to that explained above, is different in detail, and is carried out as follows:—At the left-hand end of the rocker is a jaw which carries a universal jointed vertical link, E. This link gives motion to a small crank at the end of a spindle, the bearings of which are shown at G G. The intermediate portion of these spindles is flat, and when they stand in their normal position the locking bars are free to travel over them, as shown at H; but when they are canted up (as in the case of the spindle shown at I) they offer an obstruction to the movement of the locks attached to the locking

bars. The action of the locking will be more readily understood by referring to the two front views given in

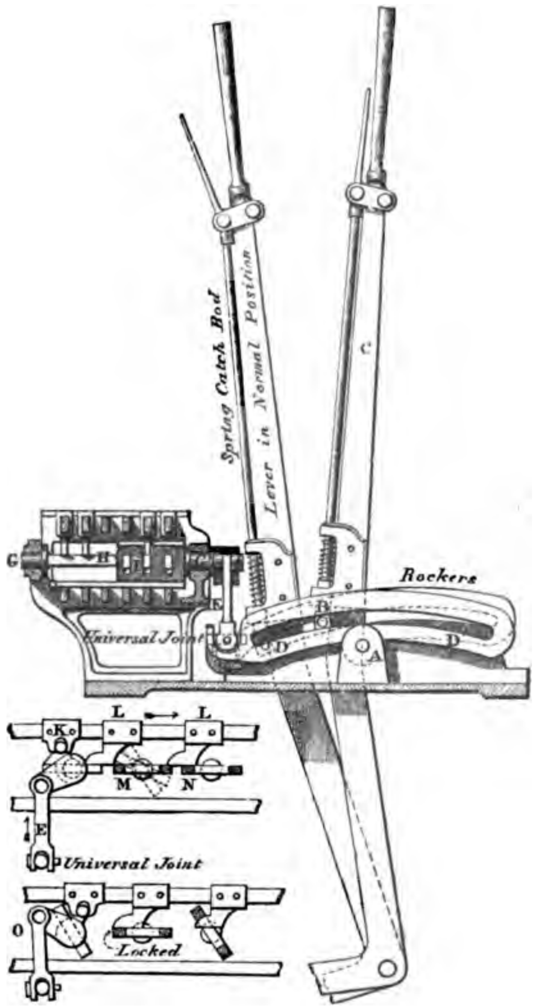


FIG. 107. Modern interlocking apparatus actuated by spring catch-rod.

the left-hand corner of fig. 107. In the upper view it is

assumed that the rocker connected with the vertical link E is in the first position, the link E is in its normal position, the crank is inclined downwards, and the flat part of the spindle is horizontal. The two other spindles, M and N, are those worked by the rockers of the two adjoining levers, but their cranks are removed in order to show a section of the spindles. Each spindle that works a locking bar is provided with a short vertical crank, the stud of which works between two horns on the locking bar, as shown at K, so that when the spindle is moved a horizontal motion is given to the bar. The locks, L L, are fixed on the locking bar in such positions that some of the spindles are free to move, as at M, and some are locked, as at N. It will now be understood that whenever the spring catch of any lever is raised its rocker is lifted, and the corresponding spindle is turned; thus a very small amount of movement of the spring catch will cant the spindle up sufficiently to prevent the appropriate locks from being moved. The spindles being connected to the rockers, may, like them, occupy three positions. These are shown at M: 1st, the normal, or horizontal position, is shown by full lines; 2nd, an intermediate position, when the main lever is being moved, as shown by dotted lines; and 3rd, the third position (also shown by dotted lines) is that which the spindle occupies when the main lever has been pulled over and the spring catch released. The right-hand end of the rocker is then depressed, and the other end with its link raised, as shown at O, in the lower front view. The third position of the rocker plays a very important part in the locking, because until that position is fully attained some of the locks are not released. If, for instance, a spindle stands locked, as shown at N, it is not released until by the movement of another spindle into the third position, shown at O, the lock on the locking

bar has travelled sufficiently in the direction of the arrow to stand over a hole in the flat spindle N, in which case the spindle can be turned up in front of the projecting beak of the lock, as shown in the case of the right-hand spindle in the lower view. The spindle, N, now prevents the return movement of the lock, and consequently the point lever which, by means of the link, O, works the left-hand spindle, cannot be moved until the flat spindle, N, has been replaced in its first or horizontal position corresponding to the lowering of the spring catch-rod of its lever into the forward notch of the quadrant.

The principle of the spring catch-rod actuation is that a signalman should not be able even to commence to make any movement of either points or signals until he has efficiently locked in their proper positions all points and signals that have any relation to the movement which he intends to make; and that until he has thoroughly completed the intended movement, and has ceased to meddle with the part of the apparatus which actually sets the points or signals in motion, all points or signals affecting the operation which he is performing must be securely locked.

The interlocking principle can be applied to any system of levers, and any lever can be interlocked with any other lever irrespectively of the work which each particular lever has to perform. Thus signal levers can interlock with signal levers or point levers, and point levers can interlock with point levers as well as with signal levers. This latter arrangement is occasionally of much consequence, as it is often desirable that a series of points should not be allowed to be put into one position, and a particular path so 'made' for a train to pass in one direction unless another series of points has been previously put in another given position, and a second

path 'made' in such a way that vehicles shunting along it, or trains which might overrun or disobey the signals, might be prevented from entering on or crossing the path of a train passing, in obedience to signals, along the first-mentioned path.

It is manifest that in most junctions or station yards there are certain lines of road which converge so that any two engines or trains travelling on them will meet, and at such places the interlocking of points with points, mentioned in the previous paragraph, is often extremely useful. A simple example of the application of this precaution may be seen in an ordinary junction, such as shown in figs. 94, 95, 96, pp. 138 and 139, in which the apparatus should be so arranged that in addition to the interlocking of the points with the signals, the points of the branch down line should be so interlocked with the points of the branch up line, that before the branch down points could be moved to set the line for a branch down train, the points of the up branch line must be first moved to set the line parallel to the branch down line, and so divert any vehicles shunting or travelling the wrong way on the up line from crossing the path of the branch down train.

As a further instance of interlocking, the gates of level crossings (fig. 108) are often interlocked with the signals, so that when the gates are shut across the railway all the signals must be at 'Danger,' and the signals cannot be lowered to 'All right' till the gates are shut against the road traffic and opened for the railway traffic. One arrangement for carrying this into effect is as follows: The gates are moved by a wheel, which by a rack and pinion movement opens or shuts all the gates simultaneously, and a lever locks the gates when they have been placed in their proper position, and this lever is made to interlock with the signals.

Any arrangement for moving all the gates simultaneously by a lever should only be applied where the signalman can from his signal box overlook and control the road

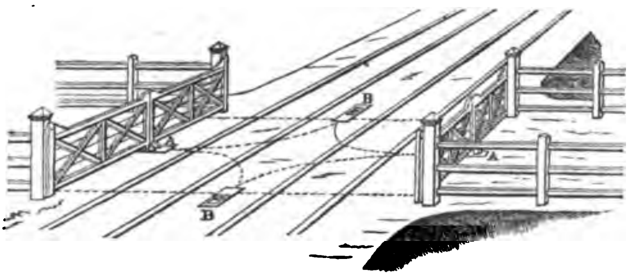


FIG. 108. Interlocking gate at level crossings.

traffic, or in cases where a porter can be stationed at the level crossing for the same purpose, as otherwise there is considerable risk that the gates in swinging to and fro may come in collision with persons or vehicles crossing the line.

Generally speaking the interlocking apparatus at present used more or less necessitates the concentration of a large number of point and signal levers in one frame, and under the hand of one man. The signalman is thus often of necessity placed a long way from some of the points which he works, and the movement of the signalman's hand is conveyed to the points by long iron rods, and a series of bell cranks. The expansion and contraction of these long rods, under the changes of temperature to which they are exposed, produce alterations in their lengths which have to be guarded against. The long rods are divided into approximately equal lengths, and their ends are connected to opposite ends of a short lever, which is pivoted at its centre (fig. 109), and placed at right angles to the long rod. Thus any alteration of length in one piece of the long rod, causing a movement of one end of

the compensating lever in one direction, is counterbalanced by the equal alteration in the length of the other part of

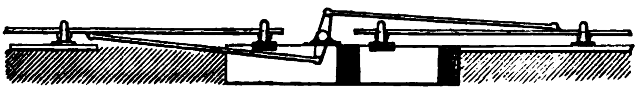


FIG. 109. Compensating lever.

the rod; this alteration of length is satisfied by the movement of the other end of the compensating lever in the opposite direction, and thus the motion of the point lever is transmitted unaltered in amount to the tongues of the points.

A truly mechanical plan, introduced on the North Eastern Railway, for imparting motion to points is shown in fig. 110. A straight rod, attached to the tongues of the points at one end, carries at its other end an upright pin, which is placed in a slot of peculiar shape in an iron plate. This iron plate is placed between guides, and is

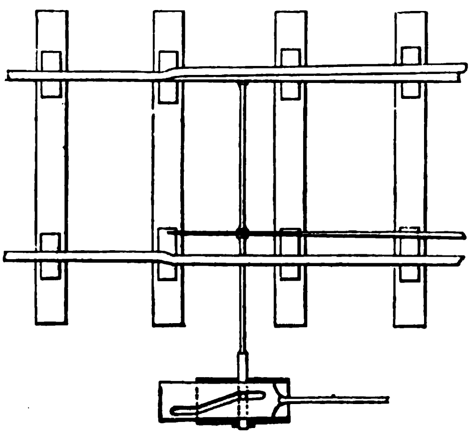


FIG. 110. North-Eastern Company's arrangement for point rods.

capable of movement to and fro in a direction at right angles to the direction of the movement of the points.

The ends of the slot are straight, and are in a direction parallel to the line of rails in which the points are fixed, and thus the first and last parts of a complete movement of the slotted plate do not affect the position of the points, but the necessary movement of the points is given by the curved part of the slot as it travels past the pin. This arrangement prevents any little inaccuracy of fitting from permitting unwarranted movement of the points, as any slight slackness of the rods or locks only affects the motion of the straight part of the slot past the pin. The position of the pin in any part of the straight portion of the slot secures the points in a very effective way, as no movement can take place between the surfaces so placed at right angles one to the other. A further advantage is that the mechanism which determines the adjustment of the points is placed close to the points themselves, and consequently the alterations in the length of the long rods from changes of temperature and other causes are unimportant in their consequences.

An objection arises to the plan of working points from a signal box at a long distance from them, from the danger of a signalman carelessly or unwittingly moving the points while a train is going over them; and there is also a danger of a rod breaking or becoming disconnected from the points without the knowledge of the signalman, in which case he might move the point lever, and so put in operation all the appropriate locking and unlocking in the apparatus, without any corresponding movement of the points themselves having taken place. Also, there is a danger with points worked from a distance of their not being completely shut, either from want of accuracy in adjustment of the working parts, or from a stone or some like impediment finding its way between the point and the stock rail.

The switch locking bar and the switch bolt, which are now almost always combined in one apparatus, obviate the above-named serious dangers. The switch locking bar (fig. 111) was designed to meet the danger of facing points being moved during the passing of a train. It consists of the following simple contrivance:—A bar, at least as long as the greatest distance between any two pairs of wheels of any vehicle in use on the railway, is placed at the side of one of the rails immediately in front of the facing points, and is connected with the rod

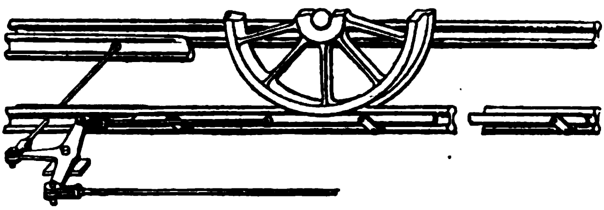


FIG. 111. Switch locking bar.

by which the points are worked. The bar is hinged on short links, so that it cannot be moved lengthways without at the same time rising. The top of the bar is level, or nearly level, with the top of the rails, when it is at either end of its stroke, but when it is in mid-position the top of the bar is some inches above the top of the rails, and it cannot occupy this position if a wheel be over the bar. As the bar is longer than the greatest distance between any two pairs of wheels, it follows that from the time at which the first pair of wheels of a train comes over the bar to the time at which the last pair of wheels leaves the bar, the bar cannot be moved, and thus, as the bar is rigidly connected with the point rod, it is impossible for a signalman to impart any movement to the points during the passage of a train over the bar.

When first introduced the bar was connected directly with the lever which worked the points, so that, as the points were moved backwards or forwards, the bar was also moved at the same time on its hinges. But recently instead of connecting the switch locking bar directly with the points, so that one cannot be moved without the other, it has been found to be more desirable to work the switch locking bar by a lever in connection with the second appliance above mentioned, viz. with the 'switch bolt.'

The purpose of the switch bolt (fig. 112), which is designed to counteract the second of the two dangers to which I referred in a previous paragragh, is to ensure that facing points are in their proper position after they have been moved by the point lever, and before the signal can be given for a train to pass over them; also to securely and firmly lock the points in their proper position, when they have been adjusted by the point lever, thus guarding against the points being disturbed by the vibration of a passing train. A transverse connecting bar, with two holes in it, is fixed at right angles to, and between the points, and a long bolt is fixed on the sleepers, between the rails, so that the bolt is shot parallel to the line of railway, through the holes in the connecting bar. When either of the holes in the connecting bar is opposite to the bolt, the bolt can be shot, but in any intermediate position of the points the bolt cannot be shot, because there would be no hole opposite to it. Thus, if the points are not put thoroughly home by the action of the point lever, the lever working the switch bolt cannot be moved; and, as the latter lever interlocks with the signal levers, no train can be signalled to approach until the points are accurately adjusted and locked in their proper position. At the same time the switch locking

bar, which is connected to the lever working the switch bolt, prevents the signalman from altering the position of the bolt while any wheel of a train is passing over the bar.

Thus, when the switch bolt and the switch locking

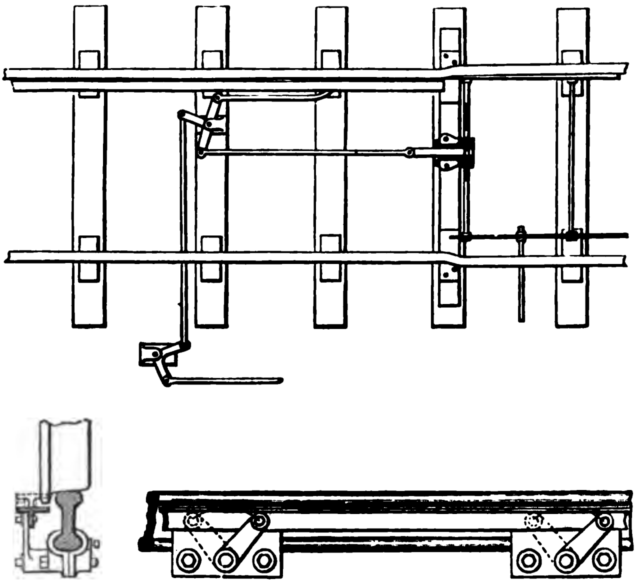


FIG. 112. Switch bolt and switch locking bar.

bar are in use, a signalman has, in order to adjust a pair of points for a train to pass over them, first to put the points in their proper position, and then to shoot the locking bolt. When these two operations are complete—and not before—he can give the signal to allow an approaching train to pass over the points. The switch locking bar at the same time prevents the bolt from being withdrawn until the whole train has passed over the bar.

There are many other contrivances and arrangements of mechanism for producing much the same results as those described in this chapter, but it is only possible

within the limits of these lectures to describe those mostly in use, and to refer to the characteristics of the more complete apparatus and to the principles observed in their construction. The signalling apparatus which have been of late adopted on our railways have attained a considerable degree of efficiency in dealing with a most complicated problem, and no doubt tend to greatly reduce the results of human fallibility.

I have especially, and at length, directed your attention to the leading principles of interlocking, because these principles are not only valuable for ensuring the safety of railway trains, but may be applied to ensure the correct working of almost all such mechanical combinations as have in part to depend on the will of other intelligences than that represented by the machine.

A clock, a steam engine, a calculating engine, may be made self-acting, that is to say, may be made to represent with almost perfect exactness the will of the person who contrives the machine; but the working of a railway, a lift, a drawbridge, the machinery for tipping coals from trucks into ships, the machinery for loading and training heavy guns, and many other kindred operations, depend on actions into which the fallible human element enters.

In these cases a variety of successive movements have to be performed, but for the initiation of each it is essential that some man in charge should decide when it is expedient that the movement in question should take place—when it should begin and when cease.

If left mechanically uncontrolled, a man in charge of any machinery, such as that to which I am referring, may by mistake initiate some movement that ought not to be begun until some other movement has been absolutely completed, and this mistake may be one which will infal-

libly cause disastrous results. For examples, among many which might be cited, a lift may be started while a passenger is entering it, or a gun-turret may be revolved before the rammer is withdrawn, or a heavy gun may be fired when the compresser is slack. Loss of life or injury to machinery may result from such mistakes—which are by no means unknown to those who have had charge of such kinds of machinery.

These mistakes may in most cases be guarded against by simple applications of the interlocking principle, under which system, while perfect freedom is given to the men in charge of the machinery to carry on their duty, they can be not only warned against, but be absolutely debarred from, committing any act which may lead to injury to the mechanism or to man.

LECTURE V.

WEIGHTS ON WHEELS OF ROLLING STOCK—NUMBER OF WHEELS TO A VEHICLE—DEAD WEIGHT OF VEHICLES — UNDERFRAMES—SPRINGS—BUFFERS—COUPLING OF VEHICLES—AXLES—TIRES—WHEEL BODIES—TIRE FASTENINGS—AXLE BOXES —LUBRICANTS—BOGIES—AMERICAN CARRIAGES—BREAKS—FRICTION AT DIFFERENT VELOCITIES—RETARDING FORCE OF BREAKS—CONTINUOUS BREAKS —BREAK EXPERIMENTS.

ROLLING STOCK of a railway, as the term is generally accepted, may or may not include the locomotive engines. I shall not, however, attempt to describe the engines, which will be dealt with by my friend Mr. Bramwell in the lectures which follow; nor shall I be able to refer otherwise than briefly to the leading characteristics of railway carriage and waggon stock. All I can hope to do, in the time at our disposal, is to give you a general view of the main features of rolling stock and to direct attention to some of the principles of its proper design and construction. Any one who wishes to follow out the subject and to study its details thoroughly must apply himself to some of the well-known published works on this important part of railway engineering.

The constructional parts of railway rolling stock, under which I comprise the wheels, the axles, and the under-frames which rest on the axles, are much the same in all cases, and are not materially affected by the modifications by which the stock is adapted to special purposes. The dimensions and designs of these constructional parts, of course, vary somewhat, but speaking generally their design is much the same in all cases. The differences which meet

the eye in ordinary railway rolling stock are in the upper work which is placed on the underframe in order to adapt the carriage or waggon to its particular function.

The weights resting on the wheels of carriage and waggon stock are very much less than the weights on the wheels of locomotives which have from 11 to 16 tons (varying with the description of engine) supported on a pair of driving wheels. The following table will give some idea of the weights on the wheels of rolling stock in ordinary use at the present time.

Weights on each pair of wheels of carriage and waggon stock.

	Empty			Loaded		
	tons	cwt.	qrs.	tons	cwt.	qrs.
First Class carriage (for 32 passengers)	4	19	2	6	1	0
Second Class carriage (for 40 passengers)	3	18	0	5	4	3
Third Class carriage (for 50 passengers)	4	3	2	5	17	0
Covered goods waggon	2	16	1	5	16	1
Open goods waggon	2	12	1	6	12	1
Coal waggon	2	4	2	6	4	2

The design of the underwork of railway rolling stock differs from that of other wheeled vehicles, from the fact that the path along which the wheels of railway vehicles travel is accurately defined, and because the curves on which it travels are laid out with special reference to the nature of the rolling stock, and to the speed at which the trains will travel. A coachman can regulate the speed of the horses he is driving and can change the direction in which the carriage on which he is seated is travelling, but an engine-driver can only control the speed of his train, and can exercise no influence on the direction in which it is to travel. All changes of direction are prescribed by the pointsman or platelayer, and consequently there is no absolute need in a railway vehicle for any such provision for turning as we see in the front part of the under-carriage of all roadway vehicles.

In ordinary rolling stock, as has been explained in a

previous lecture (p. 94), the wheels cannot even adjust themselves to the slight extent required to set themselves tangentially to the curves of the line. Railway vehicles as generally used are therefore in a mechanical point of view undoubtedly defective in the respect above mentioned, and the want of power of adjustment involves an unnecessary expenditure of the power of the locomotive in overcoming the friction of the wheel both in sliding sideways and in slipping circumferentially on the rail. A further evil ensues in the consequent and unnecessary wear and tear both to the permanent way and to many parts of the vehicles themselves.

Certain descriptions of rolling stock have, however, been constructed, and especially in the United States, on other principles, which mitigate the evils involved in wheels rigidly fixed to parallel axles. The remedy consists in the use of what are called bogies, which are, as a rule, low four-wheeled trucks, with a very short wheel base, and carrying a pivot. The ends of the body of the railway vehicle are supported on the pivots on the bogie trucks, in a way similar to that in which the forward part of an ordinary roadway carriage is supported on a pivot between the front pair of wheels. The bogie form of construction will be referred to in due course, but the rolling stock in general use on English railways, which has parallel rotating axles on which the wheels are fixed, will be first considered.

The practice of railway companies differs as to the number of wheels placed under passenger carriages, some preferring four-wheeled, and some six-wheeled carriages. As a general rule, goods and other waggons have four wheels, and the same is the case with the majority of carriages, but many of the carriages, especially for express trains, have six wheels.

There can be little doubt that in the case of an

accident happening to the springs, wheels, or axles of a carriage, a six-wheeled vehicle is much safer than one with four wheels. If any one of the springs, wheels, or axles of a four-wheeled carriage is disabled, the corner or end of the carriage over the disabled wheel or axle will probably drop; but with a six-wheeled carriage this need not happen, as the carriage would still be supported on five or four wheels, and might run a long distance without serious disaster. The disadvantage of six-wheeled carriages is that they cannot accommodate themselves to the curves of the line quite so readily as four-wheeled carriages, for the curve of the line demands that the three wheels on each side should be in a curved line, whereas the attachment of the wheels to the frame of the carriage tends to keep them in a straight line. The necessary accommodation is in practice provided by the clearance between the wheels and the rails, by a certain amount of slackness or play in the several parts of the connection between the wheels and the frames of the carriages, and perhaps by some bending of the frames themselves. There is, thus, no difficulty in constructing six-wheeled carriages properly, or in working them on railways with reasonably good curves; in fact on many lines the long six-wheeled carriages are specially selected for express trains on account of their steadiness, in addition to their other advantages referred to above. It is to be borne in mind in considering the relative safety of the different forms of carriage, that ordinary stopping trains often travel at some portions of their journey at a speed as high as that of express trains, and that an accident to an ordinary train at such a time would be as disastrous as one to an express.

In four-wheeled vehicles with parallel axles the desirable length of wheel base is governed by the sharpness of the curves of the line, since on that and on the

length of wheel base depends the possible obliquity of position of the wheels on the rails. It is to be remembered that with the amount of obliquity not only is the tractive force required to draw a carriage increased, but also that the danger of the outer leading wheel mounting the outer rail is also increased.

The length of the wheel base is a very important matter when the mode in which a railway vehicle with six or more wheels passes round a curve is considered, because if the frame and attachments which hold the axles were absolutely rigid, and there were no clearance between the flanges of the wheels and the inside edges of the rails, it would be impossible for the carriage to be worked on any but straight lines. The longer the rigid wheel base, the more clearance and play are required, and therefore, as the amount of clearance and play is more or less a fixed quantity, the length of the rigid wheel base is by this circumstance limited, and must have direct reference to the curves of minimum radius on the railways on which the vehicles are to travel. The rigidity of the wheel base of rolling stock is, however, a comparative term, as its amount varies greatly in different descriptions of underframes. The frames and the horn plates (which control the axle-boxes) of locomotives possess great strength and rigidity, in order to support and control the heavy weights and strains due to the boiler and machinery. The frames, springs, and attachments of the axle-boxes of carriages and waggons, though possessing considerable rigidity, are much more yielding than those of locomotives, and consequently the wheel base of six-wheeled carriages can be longer than the wheel base of six-wheeled locomotives.

We shall not have time to consider at length the upper works of rolling stock, which belong more perhaps to the department of a coachbuilder than to that of an

engineer, but it may be useful to briefly consider the question of weights and sizes and percentage which the paying load bears to the total load of the vehicle.

Carriages were formerly seldom or never made with more than three compartments, and those compartments were much smaller than those of modern carriages. The internal dimensions of the different descriptions of carriages now adopted as compared with those of 1845 are given below; but, to take one instance, an old first-class compartment was only 5 ft. 5 in. between the partitions, whereas now it is usually about 6 ft. 3½ in.; and, whereas formerly a full-sized carriage had three compartments, and was about 20 feet long (including the buffers), it has now four or five large compartments, and is from 29 to 36 feet long. The width and height of carriages have also been increased, in order to meet the requirements of the public. In this country the effects of competition between the Railway Companies has been conspicuously shown in the great improvements which have taken place in the convenience and comfort of passenger carriages. The case is very different in France, where there is practically little competition for railway traffic. We there see little or no improvement in the passenger carriages, which are much the same as they were twenty-five years ago. On the other hand, in the case of goods waggons we see in France considerable improvements tending to diminish the dead weight of the vehicles. In such a diminution a very tangible profit in working expenses is easily to be seen, and the stimulus of competition has not been required to point it out. The advantages of improving the carriages, as a means of inducing more people to travel, are not so apparent, though in all probability in the interests of the companies such improvements are equally valuable and profitable. There

can be little doubt that a healthy competition is in the long-run for the advantage of all parties, and that our comparative free trade in railways has, in this as in many other more important ways, been greatly to the benefit of the country.

The dead weight of rolling stock as compared with the paying load is a most interesting subject and deserves careful attention. The accompanying tables show the weight of ordinary rolling stock at the present time and in 1845, and indicate the large increase in dead weight

Comparison of length, width, and weight of carriages in 1875 *and* 1845, *and percentage of paying load in total weight.*

		Length of body outside over buffers	Width of body outside	Total weight of empty vehicle	No. of passengers	Total weight of vehicle fully loaded	Percentage of paying load to total weight of fully loaded vehicle. Total weight of fully loaded vehicle = 100
		ft. in.	ft. in.	tons cwt.	No.	tons cwt.	per cent.
First Class	1875	27 0	8 4	9 19	32	12 2	17·7
	1845	16 9	7 0	4 4	18	5 8	22·3
Second Class	1875	24 0	8 4	7 16	40	10 9	25·6
	1845	19 0	6 6	4 2	32	6 5	34·3
Third Class	1875	27 0	8 4	8 7	50	11 14	28·7
	1845	17 6	8 2	4 4	40	6 17	39·0

Comparison of weight of waggons in 1875 *and* 1845, *and percentage of paying load in total weight.*

Class of waggon		Total weight of empty vehicle	To carry	Total weight of fully loaded vehicle	Percentage of paying load. Total weight of fully loaded vehicle = 100·0
		tons cwt.	tons	tons cwt.	per cent.
Covered Goods	1875	5 9	6	11 9	52·4
	1845	3 12	6	9 12	62·5
Open Goods	1875	5 5	8	13 5	60·4
	1845	3 10	5	8 10	58·8
Coal. . . .	1875	4 9	8	12 9	64·26
	1875	4 5	8	12 5	65·3
	1875	3 19	6	9 19	60·3
	1845	3 6	6	9 6	64·5

which has taken place in the case of all classes of passenger carriages during the last 30 years. On the other hand, little change is apparent in the dead weight of goods and coal trucks. The ratio of the paying load to the total weight of the fully loaded vehicle is in each case given in the last column. This matter is of much importance with passenger carriages, but it is of much greater consequence in the case of goods and mineral waggons, as in such traffic the rates are low and the margin of profit is small. It is difficult to hit upon the happy mean between sufficient strength in rolling stock to enable it to withstand all the rough usage it has to undergo, and such an amount of lightness of construction as will give a proper percentage of paying load. Having glanced at the subject, to discuss which thoroughly would occupy much more time than we can here afford, I will now proceed to describe some of the details of the construction of rolling stock.

The several parts forming a carriage or waggon may be conveniently dealt with under two heads: first, the under-carriage; and secondly, the upper part or body of the carriages and waggons. I will confine myself here almost entirely to the under-carriage, as that is the really constructional part of rolling stock, and as such the portion which is interesting to engineers. The upper part, consisting of the carriage body or van or goods truck, may vary indefinitely, for the construction of the upper part of rolling stock is limited only by the size and strength of the under-carriage, and by the lines of minimum structure in use on a railway.

The under-carriage consists of:—

1. The underframe, which is the framework by which the body of the vehicle is supported, and by which the weight is transferred to the wheels.

2. The bearing springs, or those between the underframe and the wheels.
3. The buffer springs and the drawbar springs.
4. The axles and wheels.
5. The axle-boxes and bearings.

Fig. 113 shows the under-carriage of a modern first-class carriage with six wheels, and fig. 114 shows the under-carriage of an ordinary four-wheeled goods waggon.

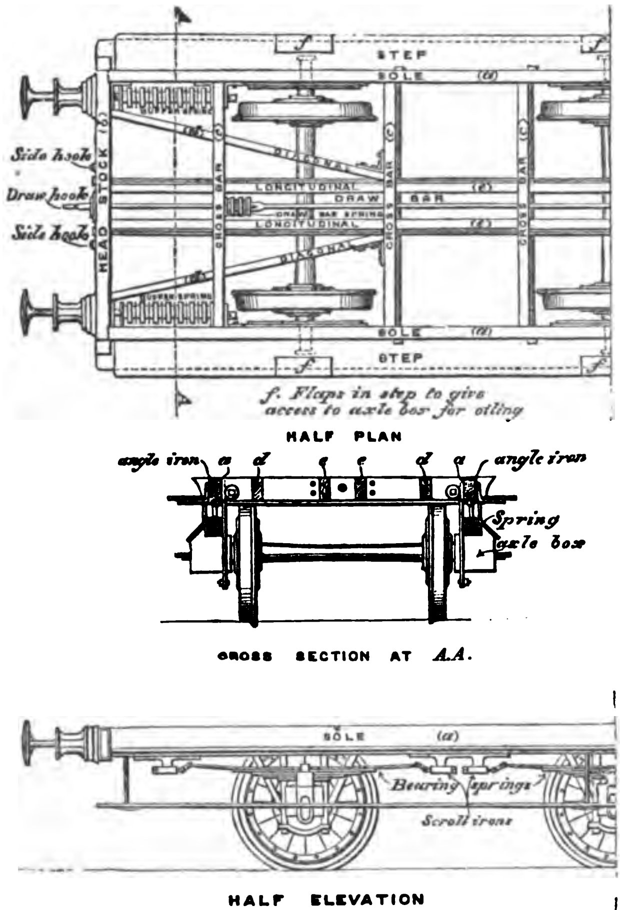


FIG. 113. Underframe of passenger carriage.

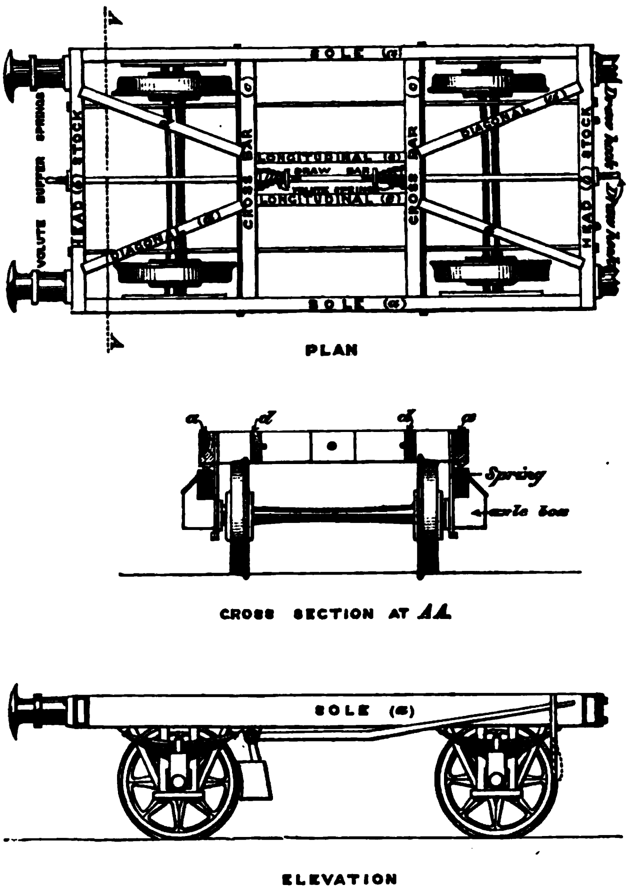


FIG. 114. Underframe of goods truck.

The constructional features of the under-carriage will apply to all rolling stock of the ordinary kind, whether for six- or for four-wheel vehicles, and whether these be carriages or goods waggons.

An underframe consists of the following parts, which are distinguished on the sketches by letters corresponding to those in the following list of the timbers composing the frame:—

(*a*) Soles, which are the side timbers, extending longitudinally from end to end of the frame.

(*b*) Head stocks or end timbers, which unite the soles at their ends, and with them form the outside timbers of the frame.

(*c*) Cross bars or transverse timbers, parallel to the head stocks.

(*d*) Diagonals, which, as their name implies, are placed in a diagonal direction, between the head stock and the centre of the frame, so as to convey the strains which come on the head stock to the framing generally, and to prevent any alteration in the shape of the framing.

(*e*) The longitudinals, which are timbers placed parallel to the soles to strengthen the head stocks and cross bars, and afford intermediate support between the soles for the floor of the body.

The scantlings of the timbers in underframes, such as those shown in figs. 113 and 114, are given in the following table:—

Scantlings of timbers for under frames of Carriage and Waggon Stock.

	Soles	Head stocks	Cross bars	Diagonals	Longitudinals
	in.	in.	in.	in.	in.
Underframe of carriage . . .	11 × 4	11 × 4½	11 × 3½	11 × 3½	11 × 3
Underframe of goods waggon (to carry 8 tons)	12 × 4	14½ × 5	12 × 4	12 × 3½	12 × 2½
Do. do. (to carry 10 tons)	12 × 4½	14½ × 5	12 × 4½	12 × 3½	12 × 2½
Underframe of coal waggon (to carry 8 tons) . . .	12 × 4	14½ × 5	12 × 4	12 × 3	9 × 3

The soles have to act as girders to carry the weight of the body from wheel to wheel, and in the case of long carriages the soles are often made with flat plates of iron or steel (shown in connection with fig. 116, p. 178), or

with deep angle irons extending in most cases from end to end of the frame, and firmly bolted to the timber.

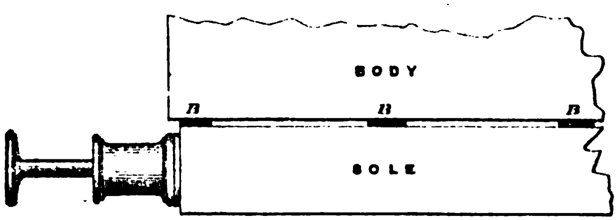
The junctions of all the timbers are made with strong iron knees and bolts. All the timber is framed with great accuracy, and the greatest care is taken to make the frame extremely strong against the various strains lengthways, crossways, and diagonally, to which a railway vehicle is constantly exposed.

No expense should be spared in securing sound seasoned timber for the whole of the underframe, as the cost of the labour to construct the frame is greatly in excess of the value of the raw material. The timber generally used for underframes is either teak or oak, both of which are very suitable for the purpose.

The underframe should be protected from the weather and from water soaking into the joints between the timbers in every practicable way, by paint or varnish, and by coverings over the joints. Timber usually decays at joints from water finding its way into the joints, however small the opening of the joint may be. In addition to its soaking downwards, water also finds its way by capillary attraction along a horizontal crack, and it is therefore desirable that the body of the carriage should not rest continuously on the underframe, but be supported by blocks, as shown in fig. 115. This arrangement allows the air to circulate freely on the top of the underframe, and prevents rot from being set up. The blocks, which are about $\frac{3}{4}$ of an inch high, are frequently made of vulcanized india-rubber, which is perhaps further useful in giving elasticity between the body and the underframe.

Many underframes of carriages and waggons, particularly on the Great Western Railway, have been made entirely of wrought iron, following the general arrangement of the frames, shown in figs. 113 and 114; but although

this material is more durable than timber, and, within the limits of the space available, a properly constructed wrought-iron frame may easily be made very much stronger than an ordinary wooden underframe, and not much heavier, iron underframes have not been generally used. It is said that repairs to an iron frame are more troublesome than to a timber frame, as any straining of an iron frame bends the whole frame, and the damage cannot be put right again without the use of a forge to straighten the bent parts, and without cutting out rivets, and riveting up the frame again. Consequently a strained wrought-iron frame is often scarcely worth the expense



B.B. Blocks of wood or vulcanised india rubber

FIG. 115.

of repairs, and its parts cannot well be worked in for other frames. If a wooden frame be strained, the damage is no doubt often localised at the joints of the framing, and can be comparatively easily set right by taking the frame to pieces, and putting it together again with perhaps a few new iron knees and bolts. But it must be allowed that these circumstances seem to show the weakness of the joints of a wooden frame, and suggest that the joints of a wrought-iron frame can be made so much stronger than the joints of a wooden frame, that a stress which will start the joints of or dismember a wooden frame would be successfully resisted by a well-constructed wrought-iron frame.

The bearing springs are made of steel plates, about

$3\frac{1}{2}$ inches wide and $\frac{3}{8}$ inch thick, arranged in the well-known way shown in fig. 116. The spring plates are held together at their centre by a band or link of wrought iron, into which the plates are firmly secured, or by a bolt passing through all the plates. The band or link is either bolted down on to the top of the axle-box, or merely fits into a mortice in the top of the axle-box, in which it is held by the weight of the carriage, while the situation of the bottom of the band in the mortice pre-

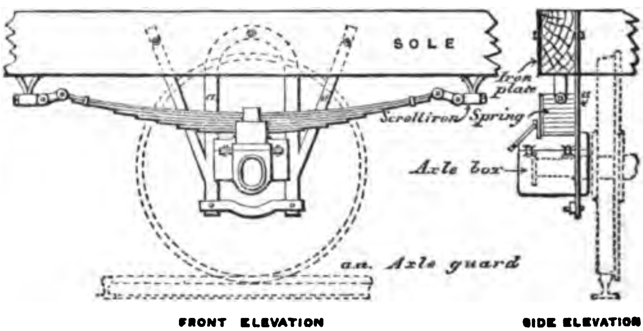


FIG. 116. Bearing spring.

vents any lateral motion taking place between the spring and the axle-box. The ends of the spring are attached to the sole by brackets, which are called 'scroll irons.'

In some cases the underframes are attached to the springs by long links or slings, which permit of a considerable amount of self-adjustment between the carriage and the path which the wheels travel in going round curves.

The length, width, and thickness of the spring plates, and their number, or, in other words, the strength of the springs, vary with the circumstances of different vehicles, and also in some cases according to the place which the spring is to occupy in the vehicle. Thus it is said that a six-wheeled carriage travels more easily if the springs

over the end wheels are shorter and stiffer than the springs over the centre wheels.

The buffer springs for carriages were formerly almost universally, and are still, in many cases, made, like bearing springs, of flat steel plates, fixed horizontally at the centre of the frame between the two centre cross bars, as shown in fig. 117. In such cases there are two springs to each carriage, placed back to back, one to receive the thrust of one pair of buffers and the other to receive the thrust of the other pair of buffers. The buffer rods rest

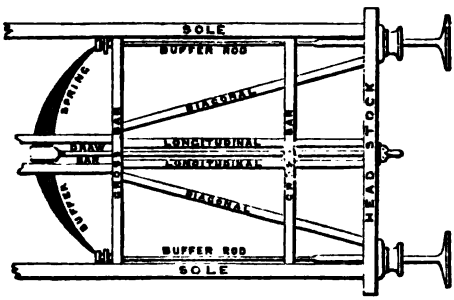


FIG. 117. Half plan of underframe showing transverse buffer and draw bar spring.

against the ends of the springs, which can turn to a slight extent on their centres, and so if one buffer be pushed in, the opposite buffer is pressed outwards by the opposite end of the spring. The draw-bar of the carriage, which is a bar in prolongation of the hook by which a carriage is attached to its neighbour, is generally made fast to the centre of the buffer spring, which thus yields slightly to the tractive force exerted on the hook of the draw-bar.

The couplings by which carriages are attached one to the other (fig. 118) consist of two elongated links of wrought iron, united by a right and left handed screw, which can be turned round so as to lengthen or shorten

the coupling. Attached to the screw is a pendent lever with a weight on its end to assist in its being turned round, and when carriages are to be coupled together, the screw should bring a good strain on the buffer springs.

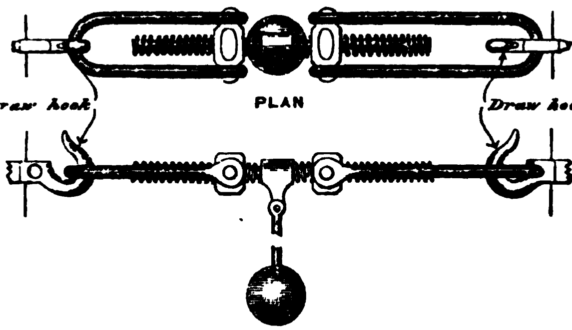


FIG. 118. Screw coupling.

When a train of carriages tightly coupled together is going round a curve, the buffers on the inside of the curve are pushed additionally inwards, and the pressure between the opposite buffers are relaxed. In order to prevent oscillation, all the buffers should be at all times pressing tightly against one another. This object is accomplished even on sharp curves by the transverse springs (fig. 117), because the pressure inwards of one buffer causes an outward pressure of the other buffer.

The long plate springs across the carriage are, however, cumbrous, and expensive, and are being to a great extent superseded by india-rubber springs, shown in fig. 119, which are formed of a number of discs of vulcanised india-rubber, enclosed in iron rings, and placed between thin discs of iron. The india-rubber discs are from 2½ to 3 in. thick, and from 6 to 8 discs form a buffer-spring of a modern carriage. The buffer as it is pushed inwards by the pull of the coupling compresses the india-rubber, which resumes its original dimensions

when released from pressure. With india-rubber springs there is no action as described above of one buffer being pushed outwards by its opposite companion being pushed inwards, but it is stated that this action is not required,

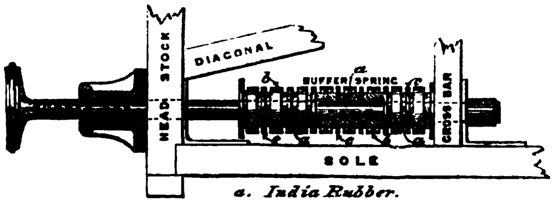


FIG. 119. India-rubber buffer springs.

because if the springs be properly made, both buffers are compressed by the screw couplings sufficiently to insure that when the train is going round curves of any ordinary radius the outer buffer will always be pressing against its opposite neighbour by the resilience of the india-rubber. The draw-bar is in such cases also furnished with similar india-rubber disc-springs.

The two draw-bars of a carriage or waggon are frequently united at their ends, so as to form a continuous bar beneath each vehicle; and thus when the draw-bars are attached together by the screw coupling between the vehicles, the traction of the engine is exerted on a continuous tightened-up chain to which each vehicle is attached, and no accumulative strain is put on the framing of the vehicles in the fore part of the train. Chains with hooks (called sidechains) are fixed to the head stocks on each side of the hook of the drawbar. These chains are attached together by the hooks at their ends, and are only intended to come into action if any coupling or draw-bar break.

In the case of waggon stock the buffer and draw-bar

springs are often made with volute springs, as shown in fig. 120, which are formed of steel plates bent into a helical form.

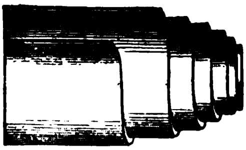


FIG. 120. Volute springs.

Goods trucks are, as a rule, not coupled tightly together by a screw coupling, but are merely attached by chains which have a considerable amount of slack when the buffers are in contact. This arrangement is adopted partly for convenience of coupling and uncoupling, but more for the increased facility which loose coupling affords for starting a heavy train. With loose couplings the engine starts each truck separately, and, to start the after-part of the train, the power of the engine is assisted by the momentum of the engine and of all the trucks which have already started and have gathered way.

Loose coupling thus permits an engine to work a heavier train than if tight screw couplings were used, because the power required to overcome the adhesion of a standing train is greater than the power necessary to drag the same train when in motion. In consequence of the frequent stopping and starting of a goods train in shunting and stopping at stations, this is an important matter; but it is a question whether the advantage of starting easily, and the consequent economy in locomotive power, is not bought at too heavy a sacrifice. The effect of loose coupling is to cause a series of jerks on all the draw-bars in starting, and a series of violent concussions on the buffers when the train is stopped, which are most seriously damaging to the rolling-stock, and frequently to the contents of the trucks. Further, the trucks of a loosely coupled train swerve continually from side to side on the rails, and produce much extra wear and tear on the permanent way. These drawbacks counterbalance

to a great extent, if not entirely, the saving in locomotive power. Saving of locomotive power, however, can be appraised with accuracy, while the cost of the wear and tear of rolling stock and permanent way can only be a matter of estimate, and thus loose coupling is still customary for a great part of the goods and mineral traffic of this country.

Some goods and mineral waggons are made without any buffers, the soles being merely prolonged beyond the head-stocks. This arrangement may perhaps save slightly in the first cost of the buffers, but it is not to be recommended, as the concussion of such trucks unrelieved by any kind of spring is seriously damaging to the whole under-frame. The saving in first cost is rather apparent than real, as the frame ought to be made stronger if no buffers are used, or else it soon wears out. There can be little doubt also that in the diminished wear and tear of rolling-stock, in the case of loosely coupled waggons, buffers amply repay their cost.

Some carriages are made without any spring buffers, and are coupled together tightly at the centre of the head-stock without any slack in the draw-bars. This arrangement is common in the United States and in other countries where the long American carriages are adopted. Tight coupling has also been used for some time past in England on the London, Brighton, and South Coast Railway for the ordinary description of passenger carriages, and fig. 121 shows the arrangement of the tight centre coupling adopted on that railway. A hard wood block (*a*) surrounded on all sides but on its rear with iron, is placed at the centre of every head-stock; a flat coupling-bar (*b*) runs through the centre of the block, and is attached at either end by a pin (*c*) to a short draw-bar (*d*) which transfers the tractive pull to the frame of the

carriage. At the other end of the draw-bar there is a screw (*e*) with a nut on it, which is turned to tighten up or slacken the coupling by a ratchet spanner (*f*) hanging vertically below the carriage. This adjusting nut presses by a ball-and-socket joint against the frame of the carriage, and allows of a small amount of necessary horizontal or vertical play of the coupling. To couple up two of these carriages a man goes beneath the carriage,

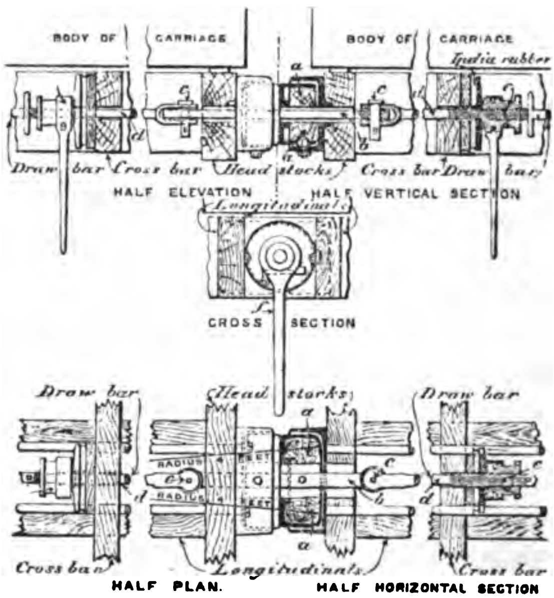


FIG. 121. Central buffer and springs.

and puts the pin through the holes in the links of the draw-bar and in the coupling-bar. A few turns of the nut by means of the ratchet spanner then tighten up the coupling, and the carriage is rigidly connected with its neighbour. The arrangement shown is used for short traffic trains which are not uncoupled for months together. If it were necessary to couple and uncouple frequently, the pin might be put in from above, through the floor of the carriage.

A train of carriages coupled together in this way resembles one large articulated carriage, and its length cannot alter under any circumstances. It is an important question whether in a collision a train coupled up tightly and with no buffers would or would not be found a bad arrangement for the passengers. The diversity between the modes of connecting carriages and the essential difference between spring and rigid buffers makes it important to consider the principles that ought to govern this subject.

Buffers have two duties to perform, the first is, that with the help of the coupling, whether elastic or non-elastic, a considerable frictional pressure may be established between their ends, so that while the ends of the carriages can slide past one another as is necessary when the train is entering on or leaving a curve on the railway, the friction may be so great that the carriages shall not be free to oscillate independently. The effect of tight coupling on the steadiness of the train will be appreciated by any one who has travelled in a carriage both before and after the coupling has been properly screwed up. The second purpose of buffers is to mitigate the effects of collisions. In providing against collisions the great thing to be aimed at is to provide an elastic medium in compressing which the momentum of the train should as far as possible be absorbed, and the longer the time which can be occupied in the process, provided that the speed of the train be meantime rateably reduced, the better. There should be, however, no recoil of the compressed medium whatever that medium may be, and this is where the ordinary buffer fails in its work. The recoil of the buffer springs in a collision often does a great deal of damage, and buffers, if they are used at all, ought to be so made that when compressed by more than the pres-

sure due to tight coupling or to the ordinary application of the breaks, or to running down an incline, the buffer springs should be incapable of free recoil, and there are no great difficulties in this being done.

Another objection to the ordinary spring-buffer, even if it were made non-recoiling, is, that in severe collisions the longitudinal stress thrown on the buffers is extremely great as compared with the strength of the buffer-springs, so that they yield readily, causing the behaviour of the carriages of the train to be to a great extent the same as would be the case if the carriages were without buffers, and were arranged in a train with an interval between each carriage, as in the case of loosely coupled mineral-trains. Thus, in the case of a severe collision of an ordinary train with an obstacle, each carriage of the train is, to a certain extent, running free till it comes into abrupt collision with the carriage immediately in front of it, and so experiences a resistance compounded of the resistance due to the obstacle and of the resistance due to the weight of all the carriages in front of the carriage in question; while the obstacle and the already comparatively stationary carriages have only at each successive impact to receive the blow of a single carriage. If, however, the carriages, instead of running with an interval between each, had been touching each other, the combined mass of the whole would have either forced its way sufficiently into the obstacle or would have crushed up the leading part of the train, so as in either case to form a long compressible buffer, relieving the passengers in the rest of the train from severe stress. Results similar to those of severe collisions exhibit themselves in a small degree in minor collisions, where the obstacle is much less than sufficient to completely arrest the progress of the train.

In estimating the advantages and disadvantages of the system of tight coupling without buffers, it must also be remembered that the tight coupling may be extremely valuable in collisions in preventing the carriages from commencing to mount one over the other, whereas the ordinary couplings which hang loosely when the buffers are compressed oppose at such times no obstacle to relative vertical movement of the carriages. But as ordinarily there is with the tight coupling no special elastic medium at the head and tail of the train to absorb, in the case of a collision, the momentum of the train, it is to be expected that the carriages nearest to that end of the train at which the collision takes place will suffer severely.

The best theoretical arrangement would probably be to concentrate the buffing arrangements at the head and tail of the train, and to couple up the intermediate carriages tightly; but in that case the vehicle carrying the buffing arrangement should be of considerable length, and should be so constructed that in the event of a severe collision it should, while being crushed, take up the momentum of the train before any serious harm happened to the rest of the carriages or to the passengers. Probably a buffing carriage which should be designed to be destroyed in the case of a severe collision could be made satisfactorily to fulfil the purposes of a passengers' luggage van, the guards in such a case being placed at each end of the central part of the train.

The wheels and axles of rolling stock are very much of one general type throughout this country; but there are considerable differences in detail. One important point of similarity consists in both wheels being fixed to the axle, so that the wheel and axle revolve together. I have already alluded at length (pp. 94 and 95) to the

disadvantages attendant on wheels fixed to non-radial axles, and I need not therefore further refer to them here. You will remember that it was explained that with such wheels and axles circumferential slipping must take place when vehicles are travelling on curved parts of the railway.

It is manifest that circumferential slipping cannot take place without torsion of the axle, and consequently the axle must be made strong enough to resist such torsional strains, in addition to being equal to its other work. A railway axle, therefore, is made of great strength and must be of the best quality of wrought iron, or of mild steel. The usual shape is shown in fig. 122. The parts of the

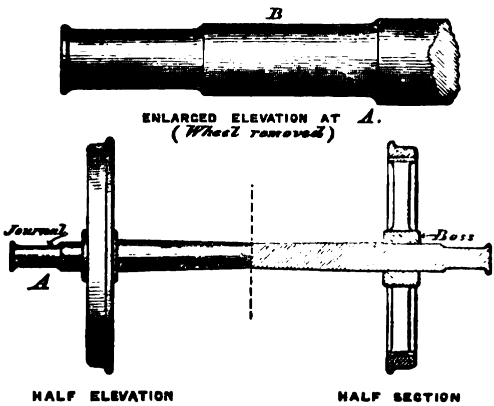


FIG. 122. Railway wheels and axles.

axle projecting beyond the wheels, on which the weight of the vehicle rests, are called the journals, and are accurately turned in a lathe, great care being given to ensure the smoothness of their surfaces. Close to the journals, but nearer to the centre of the axle, are the bosses or places on which the wheels are fixed, and these are also turned in a lathe.

It will be observed in the enlarged elevation of the end

of the axle that there are no sharp angles where the diameter of the axle alters, but that all alterations of diameter are made gradually by means of a small curve which though an arc of a small circle is technically though somewhat absurdly called a 'radius.' The avoidance of sharp re-entering angles is a matter of much consequence, not only in axles but in all parts of structures exposed to high strains, and the necessity for there being no abrupt alteration of form is the greater when the part of the structure in question is subjected to great vibratory or reciprocating strains. The constant breakage of axles in the early days of railways was the cause of attention being directed to this subject. Axles were at that time generally made with sharp angles at the changes of diameter, as shown in fig. 123, and it

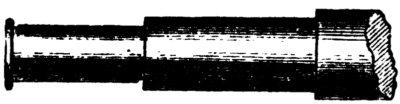


FIG. 123. Primitive axle with sharp angles.

was found that they frequently failed at the sharp angles, the fracture almost always showing signs of gradual rupture having preceded the failure. When the matter was investigated scientifically, it was seen that the abrupt change of form was the cause of the failure, and that merely adding to the sizes of the axles did not get over the difficulty. It was shown both by calculation and experiment that if an iron bar of a given uniform section will support a given weight, a bar of the same section, but forming one end of a bar of larger section, will, if the change of section be made with abrupt angles, break at or near the point of change of dimension, with a weight considerably less than in the former case. This matter is one which requires to be remembered by all engineers,

and particularly by those who have to design rolling stock of railways, and engines of all kinds. I had recently to investigate this subject, and to exemplify it I experimented on a number of paper models which are exhibited on the wall. I cut paper of good and uniform quality, which by the way is by no means a bad material for the purpose, to the form of a narrow plate joined to a much wider plate. In the one case the junction was made with sharp angles and in the other case by small curves. I subjected both forms to a pulling stress which was kept carefully in the line of the narrow plate. I measured the amount of stress by a spring balance and found, I may almost say invariably, that the plates with sharp angles broke close to the point of junction with a far less strain than those with rounded corners. The results of the experiments are, as I have said, on the walls, and I invite attention of all engineers to this most interesting subject, which has been very fully set forth in a paper read at the Royal Society by my friend Mr. Bramwell.

The axles of rolling stock are generally made of high-class wrought iron, such as Lowmoor or Bowling iron, or else of steel of a mild character, with a small percentage of carbon. A good railway axle should be capable of being bent double when cold without fracture, and great care is necessary when steel is used to secure a suitable quality of metal.

The axle is generally made smaller within the bosses of the wheel than behind the backs of the wheels, as shown at B in the enlarged elevation in fig. 122, but on some railways the axles are made of the full size, or slightly larger, within the wheel than elsewhere, in order that there may be no shoulder behind the wheel to act as an impediment to frequent examination of the axle at a place where cracks are liable to commence.

The wheels of railway rolling stock are of the well-known form shown in fig. 124, with a flange to prevent the wheels from leaving the rails. In the early days of

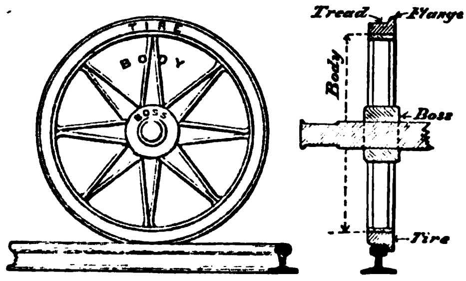


FIG. 124. Railway wheel.

colliery tram-roads the wheels of the trucks were flat, and were guided and kept on the iron plates on which the wheels ran by a flange projecting upwards from the flat plate, as shown in fig. 125, and it was not till many years afterwards that wheels were made with flanges.

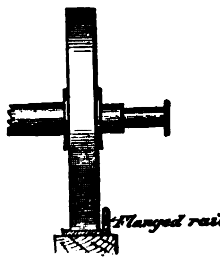


FIG. 125. Flat wheel and flanged rail.

The technical names for the parts of a railway wheel are as follows :—The 'boss' is the centre portion into which the axle fits, the 'tire' is the outside ring, the 'body' is the part between the boss and the tire. The 'tread' of the wheel is the part which runs on the rails; the 'flange' is the narrow part of larger diameter than the tread, which consequently extends downwards below the top of the rails; the 'throat' is that part of the tire at which the flange joins the tread; and the 'back' of the wheel is the portion of the tire which, when the wheel is in its position on the axle, is nearest to the opposite tire. Thus the distance between the backs of opposite wheels is the shortest transverse distance

between any part of the flanges of opposite wheels, and the distance between the throats is the longest distance between any part of the flanges. The latter measurement is of great importance as respects the gauge of the permanent way; the measurement between the backs of wheels is of equal importance in connection with the position of guard rails, check rails, and crossings.

The distance between opposite wheels and also the form of the tires are made to correspond with a standard or gauge (fig. 126) for carriage wheels, which is the complement of the platelayer's gauge, and all railway wheels are constantly tested to ascertain that they have not deviated from the leading dimensions of the gauge to which they originally conformed. The flange of the

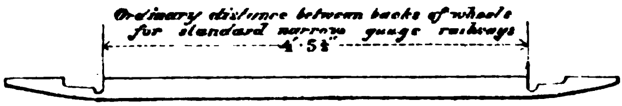


FIG. 126. Carriage wheel gauge.

wheel is continually wearing away at the throat under the friction between the wheels and the rails, so that the distance between the throats is constantly varying; but there is no appreciable wear and tear of the backs of the wheels, against which there is no constant friction. Thus the distance between the backs remains always the same so long as the wheels are in their proper position on the axles, and consequently the gauge, when it is applied between the backs, shows how much the flange has been worn in the throats, and also whether the wheels retain their proper positions on the axle.

The boss of a railway wheel is generally made of cast iron, but occasionally of wrought iron, and is accurately bored to fit the axle. The wheel is secured to the axle either by means of a key, or the key is dispensed with,

and the boss of the wheel being bored smaller than the diameter of the axle, the wheel is slightly heated and forced on to the axle by hydraulic pressure, the fit being such that the wheel, when it is cold and shrunk, remains tightly fixed in its place. The key is objectionable as weakening the boss, and in the risk there always is, in this mode of fastening, of a crack being commenced, or of some damage being set up in fitting and driving the key home.

The bodies of railway wheels are in this country usually made either of wrought iron in the form of spokes, or of solid wood. The wrought-iron bodies are made by bending the spokes so that one piece of iron forms half of two spokes and part of the periphery of the body. These bent pieces are bolted or riveted to each other, and their ends are secured to the boss or the boss itself is cast round the ends of the spokes. The wheel, which then consists of boss and body, is turned in a lathe to the proper dimension to fit the inside of the tire. Three spokes and a tire are shown so arranged in fig. 127.

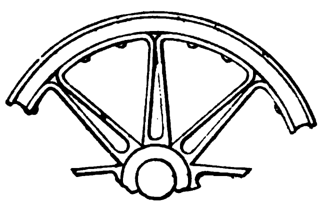


FIG. 127. Portion of iron-bodied wheel, showing arrangement of spokes.

The body of the wheel is often made slightly larger than the inside of the tire, and, in order to fix the tire on an iron body, the tire is heated so as to expand it sufficiently to receive the body. This method is objectionable on account of the uncertainty of the amount of the strain which may be so placed on the tire, and it is particularly to be deprecated in the case of steel tires. Occasionally the insides of the tires and the outsides of the wheel bodies are turned with a slight taper, and the wheel is forced into the tire by pressure,

both being cold. The best mode is probably to turn the wheel body and tire cylindrically to accurate gauges with exactly equal diameters, and to force the tire on to the body without shrinkage. After the tires are forced on they are attached to the bodies by various methods. Before, however, referring to these methods it is well to describe the other modes in which the bodies of wheels are made.

Spokes are objectionable in a railway wheel from the unnecessary resistance occasioned by their beating the air in their rapid revolution, and from their consequently raising the dust from the ballast, which finds its way into and damages the axle bearings. Solid wheels, which are made most commonly of wood but occasionally of other materials such as plate-iron or as lately suggested of *papier mâché*, are free from these objections, and possess the further advantage that they support the tire continuously, and are therefore generally adopted for all high-class carriage and waggon stock. There are, however, a very large number of iron-spoked wheels still remaining, and as the body of a wheel wears out slowly, this description of wheel will probably be in use for many years to come.

The tires of railway wheels are made in two ways. They are either rolled straight and afterwards bent round and the ends welded together, or, as is much to be preferred, they are rolled in one continuous ring without any weld. The tires are usually not cylindrical, but conical between the throat and front of the tire, and the ordinary inclination of the cone is about 1 in 20. The object of the coning is probably that each pair of wheels may have a tendency to assume a central position transversely to the line of way, and so diminish the guiding of the flanges against the wheels. I am not sure that this action takes place to any valuable extent, and there can be no doubt that un-

necessary friction and slipping is produced by making a cone continue to revolve in a straight line, or, indeed, in any line not suited to the form of the cone. Practically the conical form has the advantage of providing an excess of thickness at the part of the tread which is exposed to the greatest wear and tear, and thus conical wheels become approximately cylindrincal as they are worn away, and only become of the objectionable form shown in fig. 128 after long wear, whereas if they started as cylinders that objectionable form would be attained much earlier. Whether the practical advantages outweigh the theoretical objections is a moot point.

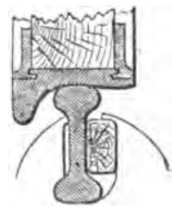


FIG. 128. Worn wheel tire on head of rail.

The importance of the subject of attaching the tires to the bodies cannot well be over-estimated when one considers the consequences which have resulted from breakages of the tires of railway wheels. The dreadful accident a year or two ago at Shipton, near Oxford, you will recollect, was due to this cause, and many other similar examples might be quoted. The early mode of fastening

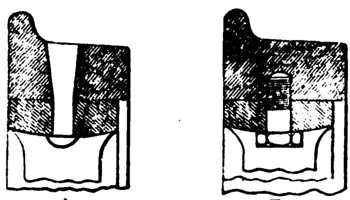


FIG. 129. Tire fastenings.

tires consisted of passing rivets or bolts completely through the tire, as shown at A, in fig. 132, a rivet-head or nut being placed on the inner side of the ring of the body. This is objectionable, as any holes through the tire weaken

it, and the objection is aggravated by the necessity that the whole of the part of the bolt or rivet within the tires should be formed with long sloping or dovetail sides, in order that as the tire wears away the hold of the bolt or rivet may not be destroyed. In some cases the tire is fastened by screws passing through the ring of the body of the wheel and tapped into the substance of the tire (as shown at B, in fig. 129), but these are almost as objectionable as bolts passing through the tire. A still more serious objection to rivets or bolts is that at best they can only hold the tire in their immediate neighbourhood, and if a fracture takes place between two rivets a piece of the tire may completely leave the body.

Many ingenious plans have consequently been brought forward for affording a continuous attachment between the tire and the body. The arrangement which has been the greatest success, and has been generally adopted, is that invented by Mr. R. C. Mansell, of the South Eastern Railway, and shown in fig. 130. The mode in which the parts are put together, and the way in which they act is as follows:—

The tire is rolled with two grooves, *g g* (fig. 130), one near each edge, and the body of the wheel is generally, but not always, made of wood, as already described. A wrought-iron ring, having a continuous flange at its outer periphery, is then placed on each side of the wheel, and the flanges on the rings fit into the grooves in the tire. The two rings, which are called retaining rings, are firmly bolted together by bolts passing through both rings and through the wooden body, and so grip the tire continuously. Every part of the tire is thus held fast, so that if the tire breaks into several pieces each piece is held to the body by the two continuous rings.

It often happens that though railway companies wish

to adopt the continuous fastening for the tires, they cannot discard all their iron-bodied wheels. Moreover, for wheels of break-vans, which have to sustain the local pressure of the break-blocks, and for engine wheels, wooden bodies are not so suitable as iron bodies, which are more strong and unyielding. Such wheels require very good holding for the bolts which keep the retaining wheels together, in order to prevent circumferential movement between the rings and the bodies. There is a well-

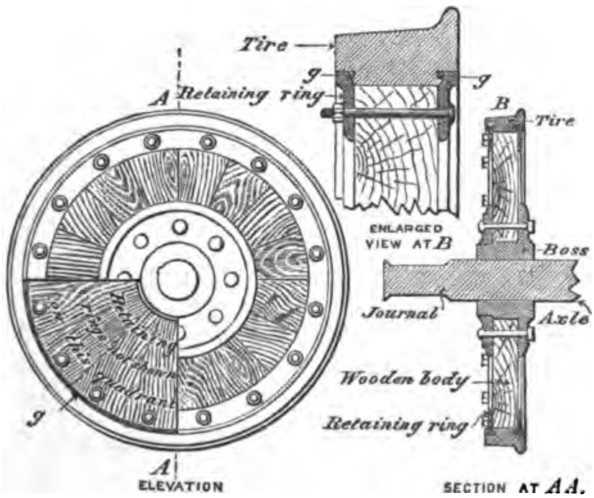
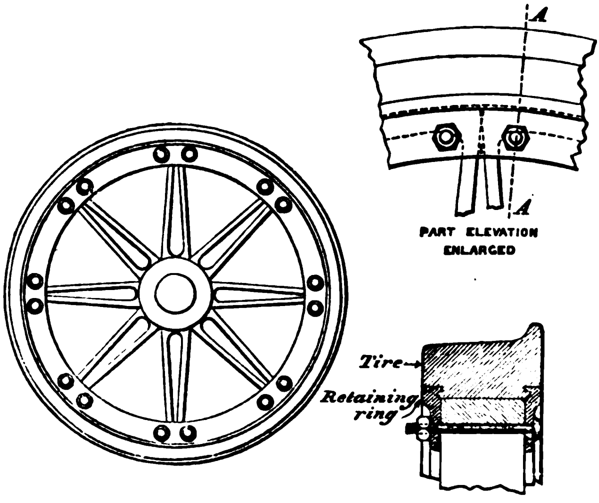


FIG. 130. Mansell's wheel.

known means, shown in fig. 131, of applying the continuous ring fastening to iron-bodied wheels by placing the bolts of the retaining rings in the angles formed between the spokes, and the circumference of the wheel. In many cases where the ring fastening is applied to iron-bodied wheels, a ring of wood is interposed between the tire and the iron body of the wheel, as shown in fig. 132. The annular cushion of wood in this case is generally about 2 inches thick, and is placcd with the grain of the wood

parallel to the circumference of the wheel. Fig. 133



ELEVATION SECTION AT A.A.

FIG. 131. Iron-bodied wheel, with retaining rings.

shows a modification of the form of ring adapted for iron

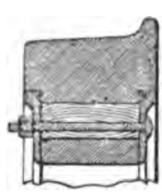


FIG. 132. Iron-bodied wheel, with annular cushion of wood.

FIG. 133. Retaining rings with double flanges.

wheels, in which the retaining rings have a flange at both their inner and outer circumference.

Fig. 134 shows a variety of other well-known arrangements for fastening wheel tires, but those which I have described are the most efficacious of all at present known.

Wheels have been made extensively in America and

in some other countries of cast iron throughout, and the part forming the tire is in that case chilled, so as to harden its surface, and the wheels are very carefully annealed. Cast-iron wheels have, however, not been adopted in England for anything but mineral waggons or other vehicles intended to travel at low speed; but it is not easy to see why, if they are successful in America, they should not be equally successful here. The quality of metal used, the mode of manufacture adopted for cast-iron wheels, and the process of annealing, require special knowledge, experience, and care, which have been more completely given to the subject in America

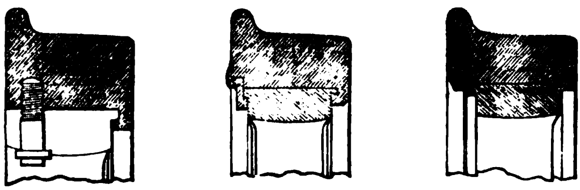


FIG. 134. Tire fastenings.

than in England; and possibly this circumstance may account for the diversity of the practice of the two countries.

The axle-box and bearings are very important parts of rolling stock, as upon their form and treatment the well-being of the stock, the tractive force required to propel a train, and the comfort of the passengers, greatly depend. The bodies of railway rolling stock are supported on the journals of the axle outside the wheels, and are therefore different to the bodies of roadway vehicles, which are always supported within the wheels. The width of the base of the supports of the bodies of railway carriages or waggons on their axles is therefore the width between the journals, and is not necessarily defined

by the gauge of the railway, because the journals, provided they be made strong enough, may project, as indeed they always do, considerably beyond the face of the wheel.

The wheels of railway vehicles, so long as no accident occurs, are always in contact with the rails, even at the highest speed, and oscillation of the carriages is not upon a 4 feet 8½ inches base, but upon a base of 6 feet 10 inches, which is the ordinary transverse dimension from centre to centre of the springs resting on the journals.

The axle-box is kept in its position, relative to the underframe of the carriage, by the springs and by the axle-guards or horn plates (shown at *a a*, in fig. 116), which are wrought-iron or steel plates bolted to the soles, and projecting downwards below the underframe, in grooves in the sides of the axle-box.

The springs rest on the top of the axle-box, and the axle-box rests on a bearing of brass or other appropriate metal which is placed on the journal, as shown in fig. 135. The friction between the carriages and the wheels takes place, therefore, between the iron or steel journal and the brass bearing. The length of the journal is usually about 8 inches, and its diameter 3½ inches. The bearing is about the same length as the journal, and embraces about one-third of its upper circumference.

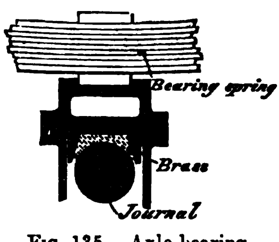


FIG. 135. Axle bearing.

The great points aimed at in a good axle-box are, good lubrication of the bearing, and the exclusion of dirt and dust. Without constant good lubrication the bearings get heated, and their surface or the surface of the journal is destroyed. The lubricants used are either specially prepared grease or oil of different kinds. The former

was the original lubricant adopted on railways, and is still much employed, though oil has by this time proved to be more efficient, considered from the point of view of its lubricating qualities, and apart from exposure and other matters. The grease is inserted in the upper part of the box through a small flap, which has a spring to keep it closed when shut, and there are holes through the brass, down which the grease trickles directly on to the surface of the journal as the axle and brass become warmed by the rotation of the journal. A great objection to grease as a lubricant is that, being applied from the top, it carries down with it on to the journal any impurity or dirt which may find its way into the upper part of the axle-box.

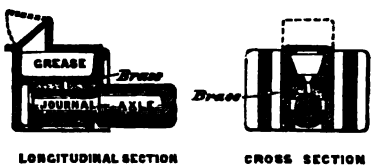


FIG. 136. Grease axle-box.

Lubrication by means of oil is usually by capillary attraction upwards. Fig. 137 shows one out of many arrangements for oil lubrication. The oil fills the lower part of the axle-box and also the interstices of an elastic horse-hair cushion, or of a woollen pad pressed upwards by small springs resting on the bottom of the box. On the pad or cushion a worsted pad is placed, with tapes like lamp-cottons which convey the oil from the pad to the journal, the under side of which the tapes touch. Fig. 138 shows an axle-box which is adapted for either grease or oil. This is a somewhat unusual plan, but it is useful to have the power of applying grease in cases of necessity to axles which are ordinarily lubricated with oil, in order to meet the troublesome but

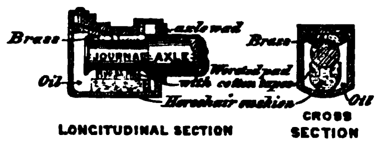


FIG. 137. Oil axle-box.

not unusual case of axles getting heated in running. If an axle lubricated with oil gets heated, it occurs in consequence either of the oil being deficient in quantity or quality, or of something being wrong with the pads and tapes. In either case the first result of a hot axle is that the tapes and pads are damaged by the heat, and cease to fulfil their purpose; it is then useless to put more oil into

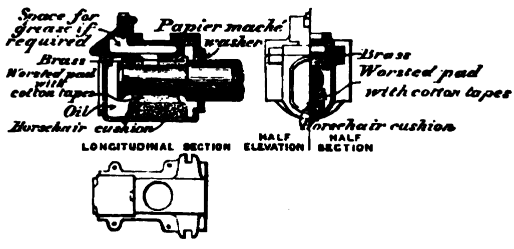


FIG. 138. Axle-box for oil or grease.

the axle-box until the pads have been replaced, which operation has to be done at leisure, and necessitates the removal of the carriage from the train. If in such cases means are provided for temporarily lubricating with grease, which requires no pad and tapes, the carriage can continue on its journey.

It is extremely difficult to keep dust and dirt from entering the axle-box, and many contrivances are adopted to prevent it as far as possible. The most usual plan is to have an annular wad of wood or papier mâché placed in a groove in the back part of the axle-box. This wad (fig. 139) is divided horizontally in two halves, which are joined by bevelled edges. The lower edge of the wad is pushed upwards in the groove in the axle-box by light springs, on which its lower edge rests, and the upper half

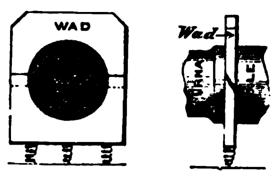


FIG. 139. Axle-wad.

of the wad is kept in contact with the lower half by its weight.

The question of lubricant is of great importance, and much care should be given to the selection of the oil or grease to be used. The grease generally employed is composed of something like the following ingredients :—

Proportions for making carriage and waggon grease.

	For winter	For summer	For very hot weather
	lbs.	lbs.	lbs.
Russian tallow . . .	214	342	426
Palm oil	240	210	210
Soda	20	18	18
	gallons	gallons	gallons
Water.	64	48	48

The quality of oil employed differs greatly on different railways, some carriage superintendents employing crude oil and others a high-class oil. It is probably wise to spare no expense in getting a good lubricating oil, as, apart from its value in lessening the tractive force required and diminishing the chances of hot axles, it saves the labour of continually oiling the axles, which is necessary with inferior oil.

The axle friction, which is a very important element, though only one element, of the total amount of resistance to a train's progress, is largely dependent on the quality of workmanship in the journals and bearings, and on the lubricant adopted. No very exact information is accessible as to the amount of force required to start a train of modern waggons or carriages, or as to the smaller force necessary to keep it in motion. Speaking broadly, the force required to start a vehicle with grease axle-boxes of good construction on a level and unyielding line, seems to be between 11 and 18 lbs. per ton of load, and to keep such a vehicle in slow motion requires a strain of from 8

to 12 lbs. per ton of load. In the case of a vehicle with good oil axle-boxes, the power required to start it will be more than that for a vehicle with grease axle-boxes, and will vary from 12 to 22 lbs. per ton of load, and to keep such a vehicle in slow motion will require a force of from 2 to 5 lbs. per ton. The great difference between the friction of rest (which is often called the adhesion) and the friction of motion in each of the above cases is very striking.

The superiority of grease over oil in reducing the friction of rest is probably accounted for by the fact that a film of grease of sensible thickness coagulates and remains between the bearings and the journals after the wheels have ceased to revolve, but the oil being fluid is to a greater extent squeezed out, and is not replaced until after motion has commenced.

It must not be supposed that the figures above mentioned as approximately representing the forces necessary for maintaining a vehicle in motion at slow speeds, by any means represent the forces (irrespective of the friction of the machinery of the locomotive, and of the resistance of the wind) required to maintain a train in rapid motion. In that case the friction of the ends of the bearings against the journals, and of the flanges against the rails, the retardation caused by more or less violent blows due to oscillation, the skewing of the vehicles on the rails, and the consequent resistances due to sideways sliding and circumferential slipping of the wheels on the rails have to be added. The total amount of resistances will thus be found to largely exceed the amounts above alluded to, and has been estimated at from 14 to 20 lbs. per ton when the train is in motion at from 40 to 60 miles an hour.

The amount of friction of the wheels against the rails

varies greatly with the amount of perfection of the road, and whether it be straight or curved. It is also modified by the amount of clearance and the amount of coning given to the treads of the wheels. Though there can be no doubt that coned wheels, apart from other disadvantages already referred to, swerve sideways on the rails, even on a straight line, and on that account cause considerable friction, and that cylindrical wheels are more fit for a straight line, yet the amount of the friction on a straight line between the rail and the wheel is not a very serious matter. On curves, however, this friction becomes of serious consequence, and it is, as has been explained, in a great measure caused by the wheels being fixed to parallel axles. Experiments on the traction of trains are generally made on straight lines, and therefore the wheel and rail friction seems to be of small importance compared with the axle friction; but there can be no doubt that if this element of wheel and rail friction were obliterated, especially in the case of the more modern lines, where sharp curves are adopted, a considerable saving of tractive force would be effected. Improvement in these respects must be looked for in the construction of carriages in which the axles may be made to run radially to the curves of the line, and in the adoption of wheels running loose on the axles.

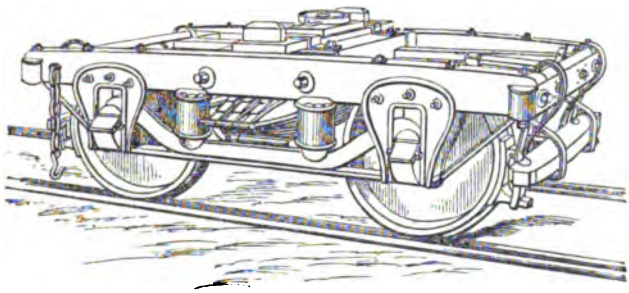
It is much to be wished that some of the great companies would set on foot careful experiments with a good dynamometer and well-devised self-recording apparatus, placed between the engine and the train, to determine these and many other interesting matters connected with the traction of trains. There can be little doubt that the knowledge gained by such an investigation would be of the highest value, and would amply repay the cost and trouble of the investigation. Such experiments were care-

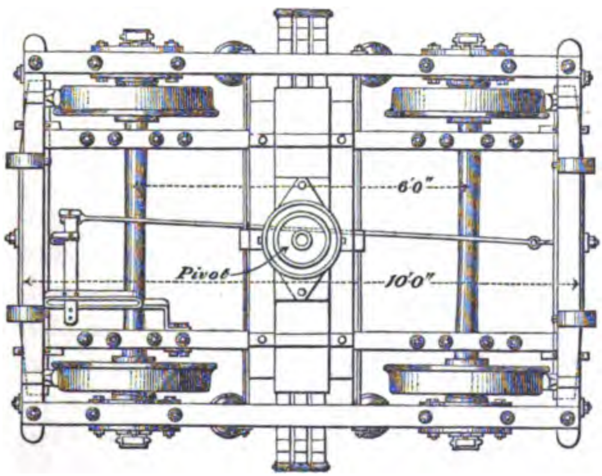
fully made by the Great Western Railway Company in 1848, but the results are only partially applicable to narrow-gauge trains, or to modern rolling stock; and, moreover, the experiments did not deal with the resistances on curves.

Before concluding the consideration of the under-carriage, the bogie mode of construction requires to be alluded to. This is a valuable contrivance for using a small wheel base for a long carriage. It is customary to refer to it as an American invention, from its having been extensively used in the United States. But the fact really is that it was an English invention for dealing with the particular circumstances of the early American railways, on which, from economical considerations, long carriages were desirable, though the railways in question had sharp curves, and were laid with a rough description of permanent way. The first bogie carriages were designed and manufactured at Messrs Stephenson's works at Newcastle, and I am told by a Newcastle man that the word 'bogie' is the slang name there for the front or turning part of an ordinary roadway carriage or waggon.

The bogie system consists in supporting each end of a carriage on a truck carrying a pivot, and running on two or more pairs of wheels placed close together. The bogie truck, having a very short wheel base, can run round sharp curves without danger, as the positions of the wheels on the railway is dependent on their position relatively to the truck, and not on their position relatively to the entire carriage. A carriage of great length, often as much as 80 feet, can thus be mounted on bogie trucks, with a rigid wheel base of no more than 7 or 8 feet, and though the axles of each bogie truck are parallel, they are from the shortness of the wheel base always more nearly radial to the curves of the

railway than the axles of ordinary carriages. Fig. 140 shows the details of the bogie truck. The American





PLAN

Fig. 140. Bogie truck.

carriages are designed as shown in fig. 141, and examples of this mode of construction have been recently brought into this country in the Pullman cars, which are exceptional carriages made on the American plan, and finished with great elaboration, not to say extravagance, in inlaid woods and gilding, so that one car sometimes costs as much as 5,000*l*. The Pullman cars are fitted with

sleeping berths, refreshment accommodation, lavatories, and w.c. arrangements, and are used in some of our fastest express trains chiefly for long journeys. The amount of

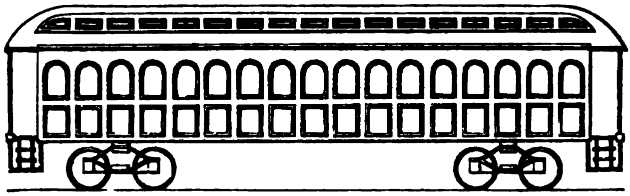


FIG. 141. American carriage.

dead weight as compared with paying load is very great in these carriages.

In the best modern ordinary bogie trucks for carriages the pivot is placed on a transverse beam which can swing slightly from side to side, and which is well provided with numerous springs as shown above in fig 140. In the Bissell bogie, which is much used for locomotives and for vehicles which have a certain amount of rigid wheel base, independent of the bogie truck, the weight of the end of the vehicle is supported on sliding surfaces on the bogie truck, but the pivot is not placed over the bogie truck but is bracketed out from it and placed between the bogie truck and the rigid wheel base of the central part of the vehicle. This arrangement is, for engines and for such vehicles as those above referred to, superior to the ordinary bogie, which however answers well for vehicles which have no rigid wheel base, and which are wholly supported on the bogie trucks. The same principle as that of the Bissell truck is carried out in carriage and waggon stock, by what is called the castor system, in which the wheel frame is pivoted at a short horizontal distance from the axles; by this contrivance the axles can place themselves radially to the curves, and the

wheels act like the castors used for furniture. There are other systems by which the axles can be made to run radially on curves, and examples of these may be seen daily in the new long carriages used on the Great Western and Great Northern Railways, in which there are appliances for enabling the axles to approximate to a radial position to the curves of the rails. There can be no doubt that the system of parallel axles is a mechanical mistake, and can only be justified by the difficulty which has been experienced in finding a satisfactory substitute. A very important matter, and one which must be kept steadily in view, is that any arrangement for making the axles self-adjusting to the radius of curves should be such as will also ensure that the wheels shall run in a true straight line on straight parts of the railway, and shall not have a tendency to diverge sideways in the event of their leaving the rails.

The internal arrangements of the ordinary American carriages do not in point of comfort compare with our best English carriages, and the grouping of so many passengers in any one carriage, even if it be fitted up like a Pullman day car, is often productive of much discomfort. In a long carriage carried on bogie frames the sides of the carriage are constructed in the form of trusses at least as high as the windows, and the trussing usually extends to the full height of the carriage. There are consequently seldom or never any doors at their sides, as they would interfere with the framework of the trussing. Thus all the passengers have to enter and leave these long carriages, which often hold 70 or 80 people, by two doors, one at each end of the carriage, and where there is much traffic great crowding, inconvenience, and delay result. In travelling, one passenger often wants a window open while another wants it shut,

and one set of passengers want to talk while others want to sleep, and in many cases, such as when invalids travel, the want of privacy is much felt. In an American carriage an open window not only affects the passengers sitting by it, but causes a draught to reach perhaps 20 or 30 people. The constant passing and repassing of passengers in and out of the carriages is disagreeable, and the conversation carried on in a large carriage is often a nuisance to many of the travellers. It is to be hoped that the arrangement of the seats and doors of the American carriages will not be generally adopted in this country, though for special purposes, such as sleeping cars, vehicles of similar length may no doubt be usefully employed.

It is a question whether all that is done by the bogie form of construction cannot be carried out on all our main English lines, which have easy curves and good permanent way, by an articulated and rigidly coupled train, in which the axles should be able to set themselves radially to curves, and intercommunication by passages between the carriages could easily be arranged when it is desired, as is now done between the travelling post-office vans.

In the case of waggon stock the bogie frame has no recommendations, as very large trucks are not advantageous, but the reverse. The convenient way of working goods traffic is to load trucks completely for particular stations, and for the goods train to drop the loaded trucks at their stations, to be unloaded after the train has gone. It is also of much importance that goods trucks should be easily manœuvred by a few men or by a single horse. Thus moderate-sized trucks, which will carry from seven to ten tons, are found the most convenient size, and such trucks can well be constructed without a bogie frame.

Time would fail me if I attempted to discuss the details of the upper works of railway carriages or waggons, and I therefore propose to leave this part of the subject, which does not, perhaps, properly belong to the province of an engineer, and I pass to the subject of Breaks.

This very important subject has recently been investigated by the Royal Commissioners on railway accidents, who have examined and experimented with most of the breaks invented up to the present time, and the results of their labours will soon be in the hands of the public.[1] It will therefore be only necessary to refer to this question in general terms, and not to enter into the details of the several new breaks, which will be found completely described, both as to their construction and performances, in the Report of the Royal Commission.

There are two modes of arresting the speed of a train, viz. by the ordinary well-known system of exerting pressure on the periphery of the wheels; or by what is called the slipper break, or by the clip break, by which pressure is exerted directly on the rails.

The slipper break (fig. 142) consists of an arrangement of levers and screws by which some of the weight of the break van is taken from the wheels and transferred to iron blocks which are pressed downwards so that they slide like sledges on the rails. The arresting power of the slipper break is due to the coefficient of friction of iron against iron multiplied by the weight which can be made to bear on the slippers. The clip break is an apparatus by which the rail is gripped by the

[1] Since the above was written, the Report of the Royal Commissioners has been published, and I have therefore, in these pages, availed myself of the official record of these experiments instead of the reports published in the engineering newspapers, which, however, were almost equally valuable and trustworthy, and which I used in delivering the present lecture.

two sides of an iron clip which through the agency of screws or levers are caused to clasp the rail tightly between them. Its power of arresting the train is independent of the weight of the train, and is due to the power of the screws or levers which cause the clip to grasp the rail. There can be no doubt that the clip break can be made

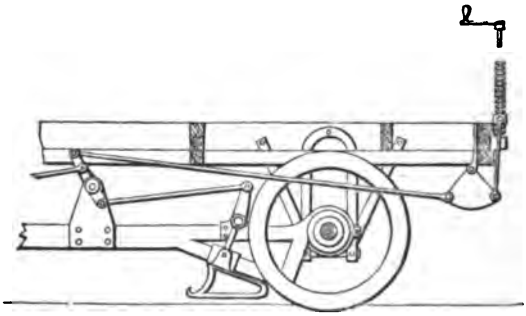


FIG. 142. Slipper break.

to act with great efficiency, and is in some respects better than the break which tends to arrest the rotation of the wheels. The disadvantage of the clip break is that it can only be satisfactorily used on a line free from junctions or points and crossings.

The break, applied to the wheels (see figs. 143 and 144), possesses for the traffic of this country the greatest practical

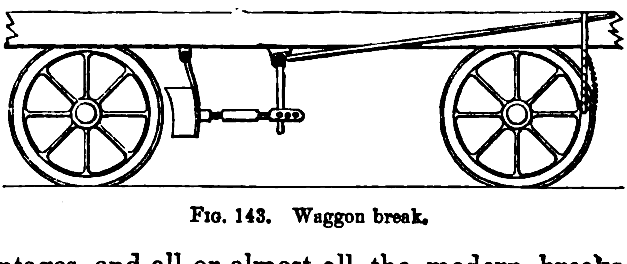


FIG. 143. Waggon break.

advantages, and all or almost all the modern breaks are based on the principle of applying the break to the wheels. One disadvantage, however, of so applying the break is, that it throws a severe strain on the wheels and journals,

and that the rotation of the wheels is often stopped altogether. Stopping the rotation of the wheels (technically called skidding the wheels) seriously diminishes the retarding power of the break, which is more efficient when the wheels are allowed to revolve at the speed of the train. There is also another objection to skidding the wheels, in that it causes the wheels to be unequally worn, and to lose their cylindrical form where they are flattened by having acted as sledges on the rails. This objection may be obviated by applying the break to a large number of wheels, and by so graduating the pressure on the break-blocks that there may be no stopping or skidding of any of the wheels.

Though it is a fact notorious to all experienced guards

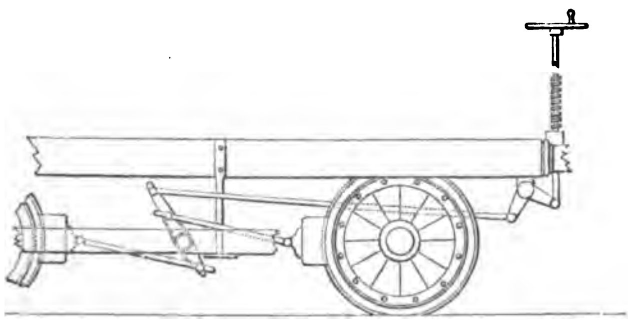


FIG. 144. Carriage break.

and engine drivers, it is perhaps desirable to explain why a greater retarding force can be obtained when the wheel is revolving than when the wheel is stopped or skidded, and slides on the rail.

In any case the only means of exerting any retarding force must necessarily be through that part of the wheel which touches the rail. All other parts of the carriage are moving forward unimpeded (except by the friction of the air which we may here neglect as being un-

important in what we are considering), and any retarding force must thus be in the nature of a retardation or drag between the wheels and the rails. It is clear that this retardation or drag must be exerted through, and within the limit of, the frictional attachment between the moving wheel and the fixed rail. We may otherwise express the strength of this frictional attachment as being the insistent weight on the wheel, multiplied by the coefficient of friction.

Now it must be borne in mind that the magnitude of this coefficient of friction is dependent not only on the nature of the surfaces of the substances in contact, but also on the speed at which these surfaces slide past one another. It is, no doubt, generally recognised that friction of rest, or adhesion as it is often called, is greater than friction of motion, but it has been generally assumed in text-books that friction of motion is independent of the velocity. This is not, however, the case, and especially at slow speeds of relative motion of the surfaces. A noteworthy instance of this is described in the 'Life of I. K. Brunel,' where it appears, from experiments and observations made at the launch of the 'Great Eastern' steamship, that between the velocity of 2 or 3 feet per second, and the lower velocity of less than one foot per second, the friction increased nearly 50 per cent.

I will assume, for simplicity's sake, though the principles under consideration are not affected by the truth of the assumption, that the materials of the surfaces in contact, both in the case of the wheel and rail on the one hand, and of the wheel and break-block on the other hand, are the same, which would be true of iron wheels and rails and iron break-blocks. We thus get rid of one of the factors which modify the coefficient of friction, and have only to consider the other factor, viz.

the relative speed of the surfaces past one another. I will also for simplicity's sake neglect the fact that the areas of the surfaces in contact may have an important bearing on the question of frictional resistance.

In the case of the wheels being skidded and sliding on the rail, the retarding force is that due to the weight of the carriage, multiplied by the coefficient of friction appropriate to the speed of the carriage along the rails, and this result is the limit of any possible retarding force under such conditions; but if by any means the wheel could be altogether prevented from sliding on the rail, and be caused to travel along it without the possibility of slipping, then the retarding force would be limited only by the amount of friction which could be produced by the pressure of the break-blocks against the wheels, which pressure can, by suitable mechanism, be made of any desired amount. Thus on the assumption that the wheel be prevented from slipping on the rail, as if it were geared to it with a toothed wheel and rack, any amount of retarding force might be obtained.

But the question will, perhaps, be asked—supposing, as is assumed to be the case, the pressure of the break-blocks against the wheel is greater than the weight of the wheel on the rail—Why, in the case of ordinary smooth wheels or smooth rails, should the wheel prefer to slide under a greater pressure exerted by the break-block instead of sliding on the rail? The answer to this is that in the assumed case the surfaces of the wheel and break-block are in rapid relative motion, whilst the surfaces of the wheel and the rail are (so long as the speed of rotation is in conformity with the speed of the carriage) relatively stationary, or nearly stationary. I have already said that the coefficient of friction between two surfaces in rapid motion is very much less than the coefficient of

friction, or adhesion as it is called, between two relatively stationary surfaces, and is also much less than the friction between two surfaces moving very slowly one over the other.

If the railway were straight, and the construction were mechanically perfect, the surface of each wheel where it touched the rail would, as regards the rail on which it is revolving, be at rest, and to prevent the wheel from sliding on the rail we should have the advantage of the whole force of friction at rest or adhesion, which is perhaps double that of the friction of motion. Owing to irregularities in the construction of both road and vehicles, and to the inevitable sliding action of the wheels when going round curves, and to the effects of vibration, and, perhaps, also to the fact that the contact between the wheel and the rail is only momentary, the full advantage of friction at rest or adhesion is not usually gained, certainly not on both wheels of a pair. The sliding motions, however, are so small even when going round curves that we have the advantage of a great part of the increased resistance to sliding due to the relatively stationary, or nearly stationary, condition of the surfaces.

Thus the wheel is to a certain extent geared to the rail, that is to say it is kept from sliding on it by a force due to the adhesion or friction of the stationary or nearly stationary touching surfaces, and within the limits of this force we can, to retard the carriages, avail ourselves of a proportionate amount of frictional resistance opposed by the break-blocks to the rotation of the wheels.

But if this proportionate amount is exceeded, or if, taking advantage of the high friction between rail and wheel when they are relatively stationary, the break-blocks are applied so as nearly to utilise all that power of

retardation, and if then some accidental increase of friction take place either at the break-block or from too hard an application of the break-block; or if the wheel from some slight cause which may exist, either in its own form or in the nature or inequality of the road, which occasions an increase in the resistance to the wheel's rotation; or if the rails be greasy in places, and unduly slippery from mud or other causes, the result of which would be a local diminution of adhesion between the surfaces, then in any of these ways the rotation of the wheel may be so much resisted, or on the other hand be so much facilitated, as to overcome the stationary friction between wheel and rail, that the wheel will begin to slip on the rail. When this slipping once commences, the friction between wheel and rail will suddenly diminish, and the wheel will skid or slide freely as a sledge on the rail, being now held from revolving by the larger friction of the break-block. When the skidding occurs, the retarding force on the train is reduced from that of stationary friction between wheel and rail as utilised by the break-block friction, to that of rapidly moving friction between wheel and rail. A well-known illustration of a similar phenomenon is the slipping of the driving-wheel of a locomotive, in which case, when once the adhesion becomes insufficient to resist the piston pressure, violent and continuous slipping immediately takes place, notwithstanding the great reduction of piston-pressure, which the mere fact of slipping occasions; an engine-driver has then to cut off the steam almost entirely, before the wheels will again take hold.

To express the condition of affairs in symbols, if we take W as the weight resting on the wheel, P the pressure exerted by mechanism on the break-block, C the coefficient of friction for surfaces at rest, and c

the coefficient of friction for surfaces in motion at the circumferential velocity of the wheel (which, in the case of a carriage travelling at the rate of a mile a minute will be 88 feet per second) we have

$W \times C$ = the friction between wheel and rail so long as no slipping is possible.

$P \times c$ = the friction between wheel and break-block.

The wheels will begin to have a tendency to slip when $P \times c$ approaches the magnitude of $W \times C$, and as soon as $P \times c$ exceeds $W \times C$ the wheels will suddenly become skidded. At the instant at which the wheels cease to revolve, the whole conditions of retardation are altered, for though we still have the force of $P \times c$ as a force preventing the rotation of the wheels, we only have as a retarding force on the rails $W \times c$ instead of $W \times C$, which is very much greater, and it is to be remembered that this state of things will occur suddenly at the moment of cessation of the wheels' revolution.

Thus, it is clear that as we increase or diminish the resistance to slipping, so we may increase or diminish the amount of friction between the break-block and the wheels.

A skilful engine-driver or guard, when he finds the wheels begin to slip or to skid, will, when there is time to do so, ease off his break until the wheels begin again to revolve with the speed due to that of the train, and he can then put the break on again cautiously, till he has increased the retarding force considerably above that due to the friction of the weight of the carriage on skidded wheels.

From what I have said on this matter of skidding, you will see of what importance it is, apart from other very cogent reasons, that in continuous or other breaks

there should be the means of graduating the pressure on the break-blocks, and of having the power of quickly releasing the break-blocks and of again quickly applying them with their proper power, and how desirable it is to have such a break as will at pleasure, either by manipulation or by some self-acting appliance, exert the highest pressure against the wheels, which shall be just short of the pressure necessary to skid the wheels or to allow the wheels to begin to slip.

The power applied to the ordinary break is generally derived from the guard's manual strength acting through the agency of levers, screws, or other mechanism, on the wooden or iron blocks which are pressed by these means against the treads of the wheels.

Until lately breaks such as the above were only applied to the wheels of the particular vehicle on which the lever or screw is placed, but continuous breaks are now often used, and will no doubt before long be universally adopted. In both cases the retarding force is, as we have seen, limited by the weight of the vehicle multiplied by the coefficient of the friction between the rails and the wheels, whether skidded or revolving. Thus in the case of an ordinary train, weighing say 160 tons, with breaks on the tender and on two break-vans, only about 25 per cent. of the weight would be controlled by the breaks, whereas, with continuous breaks, there is no difficulty in controlling by breaks nearly as much as 95 per cent. of the whole weight of the train. On the assumption of one-tenth as a coefficient of friction, we get in the case of the ordinary breaks a retarding force of about 7 tons, and in the case of continuous breaks a retarding force of about 24 tons.

The mode by which continuous breaks are applied varies considerably, but, speaking generally, these breaks may be divided into those which are worked by weights

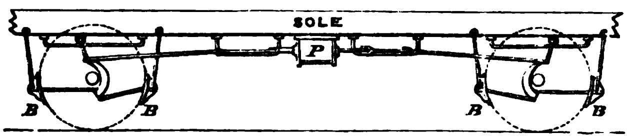
or springs, those which are actuated by the wheels of the train itself, and those which are worked by pistons actuated by steam, compressed air, or water, or by atmospheric pressure acting on a partial vacuum created on the opposite side of a piston. In the best continuous break provision is made to allow the pressure on its break-blocks to be so adjusted, or to so adjust itself, that the wheels shall not become skidded, but shall revolve at the speed best adapted to develop the greatest retarding force.

One of the most important points to be aimed at is that the break shall be capable of being applied and released with rapidity and certainty when cases of necessity arise, and that no appreciable time shall be occupied in acquiring the power necessary to apply the break with its full intensity. A further necessity of a really satisfactory break is that it shall be such as can be used in the ordinary working of a train, and not restricted to use as a special apparatus in case of a threatened accident. It is not desirable, on account of the unavoidable strains and shocks which the process occasions, that as a rule the full power of the break should be applied suddenly to a train at full speed, and it is much more advisable that the break should be applied gradually. Thus a satisfactory break is one that can be put on gradually in the every-day working of the traffic; but is also capable of being used at its highest power instantaneously when necessity arises. Breaks that are put on by releasing a spring or a weight which has previously been wound up or has been previously raised, meet the necessity of the break being available at its full power instantaneously; but they do not well carry out the other requirement of being convenient for ordinary working, as it is difficult to apply such breaks gradually or to take them off promptly.

A description of break has been much used, which is

actuated by the wheels of the train, and is worked through the wheels of the guard's van being made to act on a friction wheel, which winds up a chain and tightens up the break-blocks of any number of carriages. This is the principle of Clarke's well-known break, which is in many respects a very satisfactory apparatus. The breaks are taken off, and when not in use are kept from touching the wheels by a weight or spring under each carriage, and thus, when the breaks are required to be applied suddenly, some amount of work has to be done in raising the weights or compressing the springs in addition to that required to apply the requisite pressure. Nevertheless, these breaks can be applied with considerable rapidity and certainty, and they have stood the test of long experience on many English railways.

The remaining breaks are those which are worked by means of a piston, which by its backward or forward movement applies or releases the break-blocks (fig. 145). This description of break includes the systems of Westinghouse, Smith, and others.



B. Break Blocks
P. Piston

Fig. 145. Piston break.

The chief difference between these piston systems consists in the mode by which the pistons are actuated. Thus in the steam break, which is an extremely valuable break for engines and tenders, but which cannot well be applied to the other wheels of a train on account of the condensation of the steam in long and exposed pipes, the pistons are worked by steam pressure from the boiler of the locomo-

tive. In the Westinghouse air break a pumping engine on the locomotive compresses air which is conveyed to every piston by pipes which are flexible between the carriages. In the vacuum break the pistons are worked by atmospheric pressure against a partial vacuum, produced by means either of a steam jet or an air pump on the locomotive. In the hydraulic break the pressure on the pistons is derived from the pressure of a small hydraulic accumulator, which is raised in the well-known way by a small pump worked by a friction wheel driven off the wheel of the break van.

Much ingenuity is shown in all the systems in the arrangements for making and unmaking the joints between the carriages, which have of course to be capable of being easily and at any time uncoupled. There are also special contrivances by which, if any portion of the train breaks away from the rest of the train, the breaks are immediately applied, and the pipes are so closed by self-acting valves that the pressure in the pipes is not allowed to escape. It is not possible, here, to enter minutely into the construction and working of the several breaks; but, in conclusion, some figures will be given derived from the experiments conducted by the committee appointed by the Royal Commissioners on railway accidents. These figures show the power of the several breaks in arresting trains of known weight at known speeds, on the same railway and as nearly as possible at the same time. The varying circumstances in the experiments were thus confined to the state of the rails and the pressure of the wind. The statement of the work so performed by the different breaks is the most valuable record that exists on this very important subject.

The experiments which I have selected for quotation in the following tables are those in which the engine was

not reversed, and where sand was not employed to increase the friction on the rails. These have been chosen by preference to those in which the engine was reversed, in order to avoid confusion in comparing the effects of the different breaks. Thus the following tables do not give quite (though they do give nearly) the most favourable examples of rapidity in stopping.

TABLE I.—ORDINARY HAND BREAKS.

Application of tender and van breaks only, and by hand, to the stopping of complete trains.

Train.	Description of break used.	Weight of train during experiment.	Percentage of weight of train resting on wheels to which breaks were applied.	Details of application of breaks: Number of tender wheels to which breaks were applied	Details of application of breaks: Number of van wheels to which breaks were applied	Total number of wheels in train	Speed at signal post — Miles per hour	Train stopped in: Distance—Feet	Train stopped in: Time—Seconds
		Tons	Per cent.						
London and North Western Railway . . .	Hand break	251 1	17·1	6	8	102	45·5	2,374	62·5
Caledonian Railway . . .	Do	202·6	18·5	6	8	72	47·5	3,190	89·0
Midland Railway	Do	206·0	20·5	6	8	72	47·5	3,250	81·75
Great Northern Railway . .	Do	263·2	20·2	6	12	98	48·5	3,576	89·0
London Brighton and South Coast Railway .	Do	209·1	21·8	6	8	72	47·5	3,690	95·75

The first table shows the retarding effect of ordinary hand breaks. The weights of the trains varied from 202·6 tons to 263·2 tons, and the percentage of weight on wheels on which there were breaks varied from 17·1 per cent. to 21·8 per cent. The speed of the trains when the

breaks were applied varied from 45·5 to 48·5 miles per hour, and the distance in which the trains were stopped varied from 2,374 feet to 3,690 feet. This speed of retardation was all that could be effected by the ordinary breaks under circumstances favourable to their application, and compares very disadvantageously, as we shall see, with the least efficient of the continuous breaks.

TABLE II.—CONTINUOUS BREAKS.

Application of all available break or other power (except sand) to the stopping of complete trains.

Train.	Description of break used	Weight of train during experiment.	Percentage of weight of train resting on wheels to which breaks were applied.	Details of application of breaks: Number of tender wheels to which breaks were applied	Details of application of breaks: Number of van wheels to which breaks were applied	Details of application of breaks: Number of carriage wheels to which breaks were applied	Total number of wheels in train.	Speed at signal post: Miles per hour	Train stopped in: Distance—Feet	Train stopped in: Time—Seconds
		Tons	Per cent.							
Midland Railway No. 1 . .	Westinghouse air	207·2	94·3	6	8	52	72	52	898	20¼
Midland Railway No. 2 . .	Clarke's .	198·5	72·9	6	8	32	72	54½	1,197	22
Midland Railway No. 3 . .	Barker's .	211·1	94·4	6	8	52	72	54½	1,534	33
London and North Western Railway . . .	Clarke and Webb's .	247·9	51·0	6	8	40	102	49½	1,322	30
Lancashire and Yorkshire Railway	Fay's . .	189·8	85·0	6	8	52	72	44¼	1,150	28¼
Great Northern Railway. .	Smith's .	269·9	95·5	6	12	74	98	49½	1,433	30
London, Brighton and South Coast Railway .	Westinghouse vac.	209·7	94·6	6	8	52	72	52	1,713	36
Caledonian Railway . . .	Steele's .	201·6	82·0	6	8	52	72	48½	1,588	35

The second table shows the retarding effect of several of the well-known continuous breaks, but I think the table is only an interesting record of what was effected, and should not be taken as determining the relative merits of the different breaks. The variations in the weight of the trains, and—what is more important—the great differences in the percentage of weight resting on wheels to which breaks were applied, prevent the table from being determinate as to the advantages of each break as a retarding instrument, and there are of course several other matters connected with the mechanism of the breaks and the motive power which have to be considered in judging of the merits of each break as a machine adapted for daily use.

The best results obtained showed that with the Westinghouse automatic continuous breaks, acting on wheels carrying 94·3 per cent. of the whole weight of the train, a train of thirteen carriages travelling at the rate of 52 miles per hour could, under favourable circumstances, be brought to rest on a level line with the rails dry in a distance of 898 feet, or in about one-third of the distance which would have been travelled with hand breaks such as those in ordinary use. This is equivalent to saying that the train might have entered beneath the roof of Paddington Terminus at a speed of 50 miles an hour, and have been pulled up safely with continuous breaks before it reached the buffers at the hotel end of the station.

The state of the rails is a most important factor in the arresting power of breaks. It was shown in these experiments that the same break applied to the same train requires from 30 to 40 per cent. more space to pull up in when the rails are wet than when they are dry. The ill effect, however, of wet rails may be to some extent re-

duced by sanding the rails from well-contrived sand-boxes, which should be so arranged as to be self-acting in cases of emergency.

Probably none of the breaks have yet reached the limit of rate of retardation possible or practicable. The practicable rate of retardation, subject to the considerations to which I have above referred as to the limitation of the possible force of retardation, depends on the amount of force which may be safely administered to a train without injury to the passengers. Up to this time the power available to arrest a train with hand breaks has been altogether disproportioned to the necessities of railway travelling and to the forces at work in a train at full speed. The amount of retarding force which may be applied to a train without injury to its inmates has up to this time been much under-estimated, and it may be with confidence predicted that in future breaks will exceed in power any of those yet introduced.

LECTURE VI.

SYSTEMS OF SIGNALLING—BLOCK SYSTEM—VISIBLE ELECTRICAL SIGNALS—ELECTRICAL INSTRUMENTS—THREE-WIRE SYSTEM—TRAIN DESCRIBER—AUTOMATIC SIGNALS—ELECTRIC SLOT—GENERAL PRINCIPLES OF BLOCK SYSTEM—TEMPORARY RAILWAYS AND EXPEDIENTS—GRADIENTS FOR TEMPORARY LINES—'FELL' SYSTEM—SURFACE RAILWAYS—TEMPORARY WORKS—DRAINAGE OF TEMPORARY RAILWAYS—SLEEPERS AND RAILS FOR TEMPORARY RAILWAYS—SIMPLE INTERLOCKING—TRAIN STAFF SYSTEM—SCREW JACKS—LIFTING VEHICLES—BREAKDOWN TRAINS—NECESSITY FOR CAUTION—CONCLUSION.

IN my fourth lecture railway signalling was considered as it is carried out between the signalman and the engine-driver. We have now to notice the signalling which takes place between one signalman and another, through the agency of the electric telegraph. The time remaining at our disposal will not allow of my giving more than an outline of this somewhat complicated subject, but I shall hope to make the principles aimed at in such signalling clear, and at the same time to give a short description of a few of the various kinds of apparatus usually employed to carry out the system of electrical signalling, which is now well known as the Block System. Since the employment of the electric telegraph in working railways, the object aimed at in signalling is to preserve not an interval of time, but an interval of space, between trains. So long as the latter is preserved, no collision can take place, but the attempt to maintain an interval of time between trains is of necessity illusory. Between one signalling station and another an engine or carriage

may break down, the rails may be slippery and the train may in various ways be prevented from running accurately to time. Thus time signalling is faulty in principle, for though all the time signals may have been correctly exhibited and a proper interval of time may have been observed at a signalling station between any train and the train following it, yet before the first train reaches the succeeding signalling station the second train may have caught up the first and have run into it.

The introduction of the electric telegraph afforded means of discarding altogether the system of time signalling, and of substituting a system the object of which is, as I have said, to secure the preservation of an interval of space between the trains. The latter system received the name of the 'Block' system, either from the facility it afforded for blocking the line, and stopping the trains as required, or from the securing or blocking over of the handle of the signalling instrument in the requiring position, which was necessary in the instruments employed when the system was first introduced. The name is by no means a good one, but it has been used so long that it is not likely that it will now be discarded for a better.

The mode in which the block system is carried into effect differs slightly on different lines; that is to say, the machinery by which the signals are transmitted varies, though the principle or object aimed at is the same (with one exception, to be referred to below) on all English railways. The exception referred to is what is called the 'permissive block' system, the operation of which will be explained after the ordinary or 'absolute block' system has been treated of.

To carry out the block system a railway must be divided into telegraphic districts by signal boxes, in each of which there are signalling instruments, enabling the

signalman in it to communicate by electricity with the signal box on each side of him. Thus taking the case of one line of rails, and supposing, as shown in fig. 146,

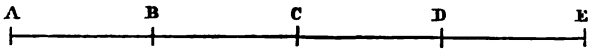


FIG. 146.

it is divided into four districts by five signal boxes, A, B, C, D, E, A will communicate with B, B will communicate with A and C, C with B and D, D with C and E, and E with D.

The districts may be of equal or unequal lengths, as may be convenient for working the traffic. Supposing, then, that a train is ready to start from A, the signalman at A will warn B of the fact. B will acknowledge the signal, and say 'send the train,' which A will do by lowering his outdoor semaphore signal. A at the same time will notify to B that the train has left; B will acknowledge the signal and will at the same time give some sort of signal in the signal box at A, which will notify to A that no other train must be sent until further orders. This last operation is called 'blocking the line,' and when the signal of B is received, A will at once put up his outdoor semaphore to the position of 'danger.' Meantime B will have asked C permission to send the train between B and C, and if B receives this permission, he will lower his semaphore arm to let the train pass his box. As soon as the train has passed B, the signalman there will notify A of its arrival, and will 'take off' the block signal and give to A the signal of 'line clear.' Precisely the same series of signals passes between every signalman from A to E, excepting only that at the intermediate signalling stations between A and E the signalman may in some cases send on the warning signal which he receives to one, or perhaps two, stations in advance, so as to avoid any necessity of check-

ing the speed of such trains as have to pass the stations in question without stopping at them.

Now suppose that a train breaks down or is delayed between C and D (fig. 147), and that a train is ready to

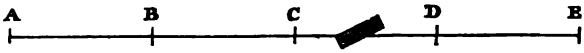


FIG. 147.

start at A or B. Previously to the break down C will have asked permission from D to dispatch the train subsequently disabled, and as soon as this has been done, D will have blocked the line at C. This block, so far as the electric signal is concerned, cannot be taken off by C, or indeed by anyone but D, who will not do so until the disabled or delayed train reaches and passes the signal box at D. Meantime, supposing that the second train is travelling between B and C, its engine-driver when the train arrives at C will find the signal of C at 'danger,' in obedience to the orders of D, and will consequently pull up at C. C will previously have blocked the line at B, when warned that the second train has passed B, and will thus have protected the second train from being run into by a succeeding train starting from A. Thus, in the case of a break-down of a train between C and D, and if trains continued to be dispatched from A, the condition of the line would be that there would be one train on each block, and a train would be standing still at each of the signal boxes B and C (fig. 148); when this state of things has occurred, no more trains could be dispatched from A until the disabled train between C and D had been removed.

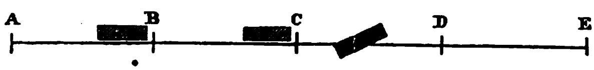


FIG. 148.

It follows, therefore, that however numerous the trains might be which were timed to be dispatched from the terminus of a line, still so long as the block signalling be

systematically carried out, no collision can take place between trains succeeding one another, because an interval of space would be preserved between all the trains. You will also see that the fact of a train travelling quickly or slowly between signalling stations does not affect the operation or correct working of the 'block system.' The fact notified by that system is simply that there is, or there is not, a train on the particular length of line between the signal boxes. Thus, though punctuality and adherence to a prearranged order of precedence of trains is eminently desirable on all grounds, these matters do not necessarily affect the correct and safe working of the block system.

The first suggestion of applying electricity to working railway traffic appears to have emanated from Sir W. F. Cooke, in the year 1842, when he published a pamphlet entitled 'Telegraphic Railways,' in which all the leading principles embodied in the present block system were enunciated, besides some others which have not yet been adopted, but which are no doubt desirable. In 1844 a length of line on the Eastern Counties Railway was signalled electrically, but public opinion was then not sufficiently educated in the necessity for improved signalling, nor in the advantages of the electric telegraph; and though it is believed that the experiment was, as a first effort, eminently satisfactory, objections were made to the system chiefly on the score of expense, and the whole subject of electric signalling as a system for the ordinary working of a railway slumbered for some years.

Meanwhile the amount and complication of railway traffic was rapidly increasing, and with the increase came some terrible collisions at junctions or in tunnels and other dangerous places, by which it was made evident that the time system of train signalling was radically faulty. Gradually, the electric telegraph was resorted to

for signalling on single lines of railway and in specially dangerous places: the new system of electric signalling soon proved its value as an exceptional arrangement for particular places, and the great advantages of the application of the block system to railway traffic in general became apparent to all.

In 1851 Mr. C. V. Walker, the telegraph engineer of the South-Eastern Railway Company, introduced a system of signalling trains by bells struck by a hammer actuated by electricity, and for upwards of twelve years the trains of that company were worked exclusively by audible electric signals. The bell signalling was eminently successful, and indeed is still the back-bone of electric train signalling. The audible electric signals have been gradually supplemented by visible electric signals, which will be described below; but though visible signals are extremely useful in all cases, and particularly where the number of trains to be signalled is large, they are not a necessity even for a complicated system of traffic, as may be seen from the fact that on the South Eastern Railway upwards of 500 trains a day were formerly often signalled by two bells, without the aid of any kind of visible electric signal.

Before referring, then, to the visible electric signals, it

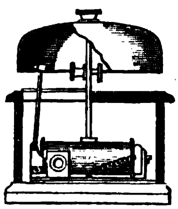


FIG. 149.
Electric bell.

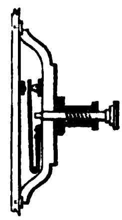


FIG. 150.
Electric key.

will be well to describe the audible system, as it existed prior to their introduction. Any number of signal boxes for a

double line of railway, A, B, C, &c., being connected together by electric wires and being furnished with galvanic batteries, two bells (fig. 149), of dissimilar sounds, are placed in each intermediate box, and in each signal box two spring buttons or, as they are technically called, 'keys' (fig. 150), are fixed. The key is the means by which the circuit of an electric wire is made and broken, and each time the key is pressed inwards the circuit is made, and the bell connected with the wires is caused thereby to ring once. In the first box A, and the last box Z, there would be only one bell and one key, because those boxes receive and give signals in connection with only one signal box, and not with two signal boxes, as is the case with the intermediate signalling stations. Taking the case of the signal box B, there would be in it two keys, one of which rings a bell in A and the other a bell in C; there would also be two bells, but the signalman at B has no power over the two bells in his own box, one of which is rung by A, and the other by C, one bell applying to the up line and one to the down line.

There is a stringent rule that every signal shall be repeated from the recipient of the signal back to the giver of the signal, in order that not only should there be a close understanding between both parties, but also that the giver of the signal may have proof that the signal which he sent has been received, and that it has been also rightly understood. An ordinary bell code is as follows:—

One blow for every up train . . .	*out.*
Two blows for every down train . . .	*out.*
Three blows for every train . . .	*in.*

Such is a code of the simplest description for train signalling; but in addition to this, there would be other signals, viz. five blows to notify that the line was ob-

structed, six blows as a testing signal to see whether the apparatus was in working order, and other signals of a similar kind. Further, in many cases it has been found necessary to distinguish, by the bell code, between different descriptions of trains, and thus gradually a bell code came to involve a much larger number of blows on the bell for signalling trains than the few signals described above.

Taking, however, three signal boxes, A, B, C, and applying to them the simple code, running only up to three strokes on the bell, and assuming that the first down train of a day is ready to start from A, the signalman at A gives *two* beats on the bell at B, to apprise the signalman there that the train is ready. B gives two beats to repeat and acknowledge the signal, and A then starts the train by lowering his outdoor semaphore signal. A then gives *two* beats a second time on the bell of B, to say the train has started, and B acknowledges the signal again by *two* beats. The first *two* beats given by B, however, block the line, and mean in words, 'I understand that a train is on the line between A and B, and no other train must be allowed to pass A without my further orders.' When the train has reached B, the signalman there gives *three* beats on the bell of A, to say 'the line is clear between A and B, and I am ready to be notified that another train is ready:' this being acknowledged by *three* beats from A, the series of signals for the first train is complete as between A and B. While the train is passing between A and B, B will signal forward the warning signal of *two* beats to C, and if C replies by *two* beats, B will lower his outdoor semaphore signal before the train reaches B, so that its progress may not be checked; otherwise, and unless he receives *two* beats from C, he will detain the train at B by his outdoor signals.

It will be observed that there is a seeming contradiction in the signalman at B replying to the

request of the signalman at A for permission to send a train by saying on the bell signal 'Yes, send the train,' but turning the needle at the same time to the prohibitory signal of 'Train on line.' This contradiction is more apparent than real, and is not found to lead to mistakes in working. The important part of the block system is to promptly block the line behind a train to prevent another following it till the first train gets clear of the next station, and it is better to do this even before the first train passes than to delay the signal for the time necessary to send another signal to say the train has passed. At the same time it cannot be denied that it is undesirable in any system of communication to have signals which, for however short a time or however well understood, state that which is not the case.

It is a most important condition of any code that a signal shall not be considered as having been given, nor shall it be acted on, until it has been acknowledged and repeated, and it is of especial consequence that this rule should be rigidly enforced with a code of signals which are exclusively audible. When the combined system of audible and visible signals is considered, it will be seen that it is not of the same consequence that each particular signal should be repeated; and in such cases a common acknowledgment signal is often used, applicable to all signals given, and the special audible signal is not repeated.

In some places where the audible code, from the necessity of distinguishing between different descriptions of trains, becomes complicated, an index or automatic counter, to register the number of strokes given and received, is desirable, even if a regular system of visible signals be not employed. It is, however, astonishing how remarkably skilled the ear of a practised signalman becomes to instantaneously appreciating with correctness

the number of strokes given, and how rarely mistakes have been made in this respect. Notwithstanding this fact, an index counter is undoubtedly valuable, as it affords the check of the eye upon the ear, and should render a mistake in counting almost impossible.

Although it has been shown, from the experience of many years, that a well-devised system of exclusively audible electric signals can be worked efficiently, even under the circumstances of a crowded railway, the addition of visible electric signals is doubtless extremely valuable from their affording a record of the signal given, which is retained before the eye of the signalman until another signal is required to take its place.

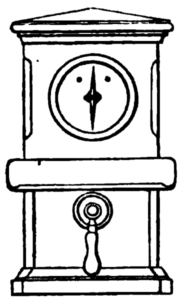


FIG. 151. Electric telegraph needle speaking instrument

The original instruments adopted for visible electric train signalling were either telegraph-speaking instruments (fig. 151), or modifications of them, in which a magnetised needle is deflected to the right or to the left from a central or neutral position, in accordance with the movement of a pendent handle. In telegraphing trains, only two visible signals are really necessary, viz. 'Line clear' and 'Train on line,' and these are easily given by deflecting the needle to the right for one of the above signals, and to the left for the other signal.

To instruments of this sort there were these great objections, viz. that the deflection of the needle was momentary, and that, consequently, accuracy of signalling depended on the signalman's recollection of the time at which a signal was sent, and of the sequence of the signals. The difficulty was sought to be overcome by entering all signals in a book; but this is only a palliation of an evil, as signalmen will trust to their memory, and,

indeed, can scarcely consult a book systematically in working a crowded line.

About 1854 the London and North Western Railway adopted electric instruments which were designed to get rid of the above objections. By these instruments (fig. 152) three signals could be given on each dial, viz. 'Train on line,' 'Line clear,' and 'Line blocked.' The two former of these signals were given by deflecting the needle to the right or to the left, by means of the ordinary pendent handles, and a pin was provided to each handle, which could be inserted through a hole in the handle into the fixed frame of the instrument, so as to retain the needle in either position. The third signal, namely 'Line blocked,' was given by the needle being in the vertical position, and indicated that an accident had happened. This last signal could not only be given from each signal box by placing the pendent handles in a vertical position, but could also be made by cutting the telegraph wires, and provision was made for this to be done at numerous spots on the line, intermediate between the signal boxes, by bringing a portion of the wire down the telegraph posts to within reach from the ground. The guard of any disabled train could thus at once block either or both lines, as the signal could be given to signal boxes on either or both sides of the break-down. This arrangement, which has not been generally further adopted, is only of use in the case of an accident blocking both lines, in which event not a moment should be lost in endeavouring to stop any trains coming towards the scene of the accident by flags, lamps, or fog-signals. The electric signal would be only valuable if the approaching train had not already passed the signalling stations to which the 'line

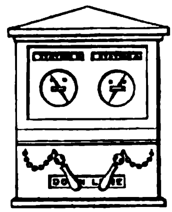


FIG. 152. Train signalling needle instrument.

blocked' signal would be given by cutting the wires, and in that case there would be ample time to stop the train by hand signals. If the train had passed the signalling stations, the signal would of course be more than useless, as it would tend to create a false feeling of security. Moreover, cutting the wire completely disabled the train telegraph, which, at such a time, might be extremely useful in working a code of signals; and, lastly, it necessitated repairs at a time when they were peculiarly inconvenient. Under the absolute block system, the fact of a train not being telegraphed back as having arrived at the end of a district a few minutes after its entry on that district, should be an indication to the signalman at both ends of the signalling district in question that something is wrong, and this is all the information that was imparted by cutting the wire.

On the London and North Western Railway, however, and on some other lines, the 'absolute block' system was not at first used, but what is called the 'permissive block' was adopted. Under it the facility for instantly informing the signalmen of a break-down might be useful. Under the 'permissive block' system no signalman is allowed to give an 'all right' signal to an engine-driver till he has received a signal of 'line clear' by telegraph from the signal box in advance; his duty is, however, not to altogether stop a train succeeding one already on his district, but to arrest it temporarily, and, after warning the engine-driver that the line is not yet free, to permit him to proceed cautiously. This system is consequently 'permissive' of two or three trains being on one district at a time, and is much inferior to the absolute block system, which is now almost universally employed wherever telegraphic signalling is in use.

Thus though the needle instrument is still retained on many lines for train signalling, the third signal of 'Line

blocked' is generally discarded. The two signals given are expressed by right or left hand deflection of the needle, and express the signals 'train on line' and 'line clear,' while the vertical position of the needle usually signifies that no signal is at the moment being given, and that for the time being all electrical signalling is in abeyance.

In other instruments of a similar description—introduced many years subsequently (fig. 153)—a small piece of card is attached to the needle, and on one side of the centre of the card are the words 'Train on line' on a red ground, and on the other side 'Line clear' on a white or green ground. A hole, large enough to disclose at one time half the card, is cut in the face of a dial fixed in front of the needle, and thus, by deflecting the needle to the left or the right, the words 'Train on line' or 'Line clear' are in turn exhibited through the hole in the dial. The absence of signalling is, in such cases, indicated by the needle being in a vertical position, when half of one inscription and half of the other appear parti-coloured through the hole. The needle which carries the card is either moved by pendent handles, similar to those of the speaking needle instrument, with pegs for blocking over the needle, or by means of spring buttons, which are pressed in by the signalman's hand, and are retained in their position by a pin. There is little difference between this instrument and the former, but it is perhaps slightly more distinct in the information which it conveys. The difference between the two is much the same as that between an ordinary needle compass, in which the needle points to divisions on a fixed card, and a mariner's compass, in which the card is mounted on the needle, and travels with it.

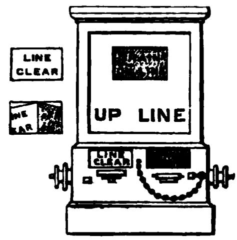


FIG. 153. Needle instrument with card.

About 1852 some needle instruments (figs. 154 and 155), worked by electro magnets, were introduced for train signalling, and have since been much used. In these instruments there are two needles for each line in each signal box, which are painted respectively red and black.

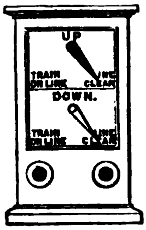


Fig. 154.

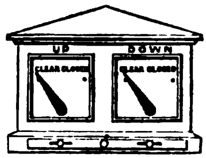


Fig. 155.

Electro magnet needle instruments.

The black needle shows the last signal received at any signal box, and the red needle shows the last signal sent from the same signal box. Thus a signalman has before him not only the order sent to him from a distant signal box, but also a record of the order which he himself has last sent to the other signal box. The black needles can only be affected by currents of electricity sent from another signal box, and the signalman in whose box they are placed cannot alter their position.

I do not propose to trouble you with a description of all the different instruments by which visible signals are given by electricity. You are probably familiar with the needle instruments, and can see that it is susceptible of many modifications for the purpose. I will therefore content myself by describing another instrument, which is very commonly used now-a-days, viz. the Miniature Electric Semaphore.

The electric miniature semaphore signal, shown on fig. 156, was first introduced in 1855 on the South Eastern Railway, as an improvement on the needles above described. The point aimed at was to use a signal which

should be identical in appearance with the outdoor semaphore signals, and so to make electric signalling the counterpart of the outdoor system. The electric semaphore signal which is now extensively used on many lines is a post with two arms for each line of rails; and the arm on one side of the post is painted red, and the other arm white. The red arm is the means by which the signal is

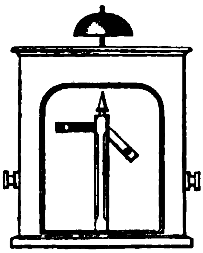


FIG. 156. Miniature electric semaphore (two arms).

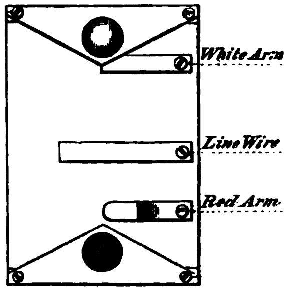


FIG. 157. Electric semaphore key.

received from a distance, and the white arm is an indicator of the signal last sent. There is a key (fig. 157) for working the semaphore signal, similar to the key used for sounding the bells; but it is double, and possesses two knobs, which are respectively black and white. By pressing the white knob at signal box B, the red semaphore arm at signal box A is lowered, and at the same time the white arm at B is lowered, in agreement with the movement imparted to the red arm at A. Conversely, pressing the black knob at B raises the red arm at A, and the white arm in the box at B. Thus pressing the white knob takes off the signal, and pressing the black knob puts it on. The bells are rung in accordance with any prearranged code, but the instruments are so made that when it is necessary to give five or six blows on the bell to describe the nature of the train about to pass, the first blow alters the position of the semaphore

arm if necessary, and the subsequent blows do not affect its position.

It is convenient that the miniature semaphores should be placed so as to face the signalman from the direction of the next signal box with which they are in communication. Thus an electric semaphore communicating with a signal box to the west of B would be placed on the west side of B's signal box, and that communicating with a box on the east would be placed on the east side of B's signal box. The miniature semaphores are in my opinion very valuable signals, for they are extremely simple, not liable to derangement, and tell their tale not only in a most efficient manner, but also in the same way as the outdoor signals.

A form of miniature semaphore, but worked by means of three wires to each instrument, instead of one wire as above described, and with only one arm (fig. 158) instead of two arms, was introduced by Mr. W. H. Preece, and was largely adopted on some railways.

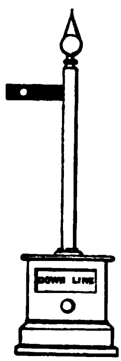


FIG. 158.
Miniature electric semaphore (one arm).

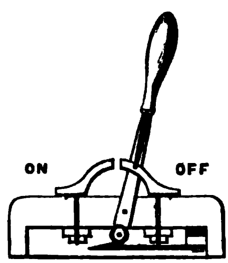


FIG. 159.
Electric switch handle.

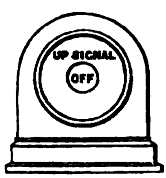


FIG. 160.
Electric indicator dial.

This miniature semaphore is worked by a switch handle (fig. 159), resembling the lever by which the outside semaphore arms are raised and lowered, and a

separate single key is used for ringing the bell. The acknowledgment of the signal sent is given on a dial (fig. 160), on which the words 'on' and 'off' appear, in agreement with the position of the semaphore arm at the distant station. It is in the visible acknowledgment of the signals sent that the peculiarities of the three-wire system consist; and, although the system is somewhat more expensive, and introduces some undesirable complications, it possesses some undoubted advantages. One great necessity of telegraphic signalling is, that the signals sent should be correctly acknowledged, and that a signalman at A should not have it in his power to mistake and acknowledge a signal of 'Train on line' sent from B, as being a signal of 'Line clear.' With instruments worked by one wire it is true that the visible signal is exhibited both in the cabin of the sender and of the recipient, but there is no absolute security that the recipient has correctly received the exact signal despatched by the sender, nor that a signal may not have been altered by some defect in the electric circuit between the two cabins. The mere acknowledgment sent back by the recipient by a beat on the bell, which is the audible acknowledgment for all signals, only means that a signal has been received, and it is possible, though improbable with the present powerful instruments, that a false signal has been sent, and that when B meant to raise the semaphore at A, he has, from some cause, not raised it as he intended to do.

This difficulty is met by the three-wire system in the following way, to explain which the case of the two signal boxes, A and B, must be again considered. The miniature semaphore is so made and so connected with three telegraph wires, x, y, and z, that when the miniature semaphore arm is raised at A by the signalman at B, the wires x and y are placed in contact by the same

mechanism that raises the miniature semaphore arm. An electric circuit is made by the contact of x and y, which enables a signal to be given by A to B which will correctly acknowledge the particular signal sent by B—viz. that of the raising of the semaphore arm, and will acknowledge no other. When the acknowledgment of the signal is given by pressing the bell key at A, a current will pass to B, which will ring a bell at B, and turn the indicator at B to the word 'on,' but which cannot turn it to the word 'off,' nor allow it to remain at the word 'off.' Similarly, if the semaphore arm is lowered at A, the act of lowering it disconnects the wires x and y, and puts the wires y and z in contact; a different circuit is thus completed, and by this circuit, when the same key at A is pressed to acknowledge the lowering of the semaphore arm at B, the word 'off' can only appear on the indicator at B, and the word 'on' cannot appear. In this way a signal cannot be acknowledged except in the sense in which it was sent, and in the way in which it is visibly exhibited in the cabin of the recipient.

It is right to remark, however, that the danger apprehended and guarded against by the three-wire system has not been found to exist to any serious extent, and that though theoretically more perfect than a system worked by one wire, the three-wire system is exposed to the disadvantages of increased complication of mechanism and of considerable extra expense.

In some situations it is necessary that a signalman shall communicate with and instruct a signalman intermediate between himself and the signalman with whom he ordinarily communicates, but who does not work a block district. This sometimes occurs in the case of sidings, which are only occasionally used. In such a case the switch handles (fig. 159), which work the miniature

semaphores, are connected together both at the main station and at a signal box at the sidings in a mechanical apparatus similar to the locking apparatus of the point and signal levers, so that the signalman is not able to move the miniature switches, and so signal to the sidings that the points there may be used, until he has first put the switch handle of the miniature main line semaphores at the next block signalling station at 'danger;' and conversely, that he cannot move the switch to lower the main line miniature semaphore until he has first put the miniature semaphore at the siding to 'danger.'

A very useful instrument, called a Train Describer and shown in fig. 161, has been recently introduced. Its purpose is to simplify the bell code, and get rid of many complex audible signals in signal boxes where it is necessary not only to describe a train as an 'up' or 'down' train, but to tell the signalman, in advance, from what place it is arriving or whither it is going. Thus, on the Cannon Street line of the South Eastern Railway, where this train describer is in use, it is necessary to discrimate between no less than eleven sorts of trains, and to do this on bells entails an inconvenient amount of ringing.

The train describer has a dial which is usually fixed below the ordinary electric semaphore, which is worked as above described, and on the dial there are a number of names (corresponding to the number of descriptions of trains using the line) painted in small circles near its circumference. A large needle driven by clockwork is controlled by electricity from the next signal box, and points to any of the names on the same principle as that of Sir C. Wheatstone's A B C telegraphic speaking instrument. Each complete apparatus consists of two describers, one the sender and the other the receiver. The sender

instrument is furnished with small movable handles placed radially outside the circumference of the dial, and opposite to the small circles containing the names of the trains. When the instruments are to be used, the signalman gives a warning signal on the bell, and if, for instance, an 'up Mid Kent' train is coming, the handle opposite those words is pulled forward on the up sender instrument to the position shown in the figure, and the needles both on the up sender instrument at signal box A and on the up receiver instrument in signal box B, point to 'Mid Kent.' The signalman thus has a visible record of what kind of train is coming; he has not to trust to his memory at all, and the immense amount of ringing necessary under a complex bell code is avoided.

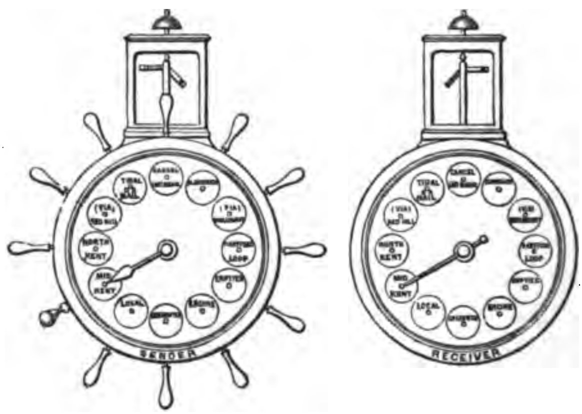


FIG. 161. Train describer.

Several plans have been suggested for enabling signalmen to exhibit signals on the engine itself; and, indeed, the mere exhibition of electric signals on the engine has been practically carried out in the well-known electric train telegraph, which gives communication between passengers, guards, and engine-drivers. An arrangement has also been worked out experimentally, by which every train can automatically give and receive the signals of the block system, to and from the engine as it passes along the

line. However well such a system may be hereafter carried out, it will not probably dispense with signalmen by the side of the line, and with the use of fixed signals. A signalman is useful not only as an exhibitor of signals, but as a watchman over the signals, to see that they work correctly, and over the trains as they pass, to detect anything that may be wrong in them; and it is in the highest degree desirable that there may be persons at specified places who can act in an emergency with experienced intelligence. For these reasons automatic signals, whether outdoor signals or electric signals, have never yet been found to be a satisfactory substitute for signalmen, while further they are exposed to the drawback that their mechanism may break down at the most important moment, and that defects in their working may not be discovered till a disaster has occurred.

The above remarks do not, however, apply to any system which, without dispensing with the superintendence of a signalman, should render it impossible for him to exhibit an outdoor signal contrary to the orders of the miniature electric signals in his cabin; and it must be remembered that it is by the outdoor signals, which are seen by the engine-drivers, and not by the telegraph signal, which is inside the signal box, that a train is actually controlled. At present a disagreement may occur between the electric and the outdoor signals, and there is no actual certainty that a signalman obeys the orders of another signalman, who may be perhaps four or five miles distant, but to whose orders, expressed by the telegraph, it is his duty to conform. In the case of an outdoor signal you will remember it has been rendered impossible for disagreement to take place between signalmen who by mechanical means jointly control a signal though it may be perhaps 1,000 yards distant from one of them; because, by means of the slotted signal rods, the com-

bined assent of any number of men may be necessary for the movement of the signal. The same sort of control over a signal removed in this case to any distance from one of the signalmen, has been attained in what is called the 'electric slot signal' (fig. 162), which is a promising contrivance, though it has not yet been carried much further than experimental working. The title has been probably given from the similarity of results attained by the mechanical and electric slot; but in all other respects it is an inappropriate name, as the arrangement of the slot forms no part of its mechanism.

A is a lever consisting of a pair of wrought-iron plates side by side, with a space of about three inches between them. This lever is worked by a connecting rod from the signal lever. C is a clutch pivoted to A. H is a hammer so pivoted that a small upward movement of A will raise H to the nearly vertical position in which it is shown in the figure. S is a lever working on the same pivot as A, and works the signal. When S is free, and not held up by the clutch C, the signal flies to 'danger.' M is an electro-magnet, and *d* a detent.

When M is magnetised by a current of electricity from the station in advance, the hammer H is held in its vertical position by attraction to M, and is further secured by the detent *d*, also worked by the electro-magnet M.

The maintenance of a current of electricity by magnetising M holds up H, but if the electric circuit be broken, the electro-magnet M ceases to hold up H, which then falls by gravity on to the upper end of the clutch C, thus releasing the bar S, which is held by the clutch C, and allows the counter-weight of the signal to place the signal at 'danger.'

The clutch C is so weighted as to catch S unless H is lying on the upper end of the clutch; in that case A may

be moved up and down, but the clutch will not grasp S, which will in such case be unaffected by the movement.

The signalman in advance can thus, by breaking the electric circuit, prevent H from being held up, and by so preventing the clutch from holding up the lever S, he can take away from the signalman at the signal lever all power of lowering his signal to 'all right.' Similarly, if the signal

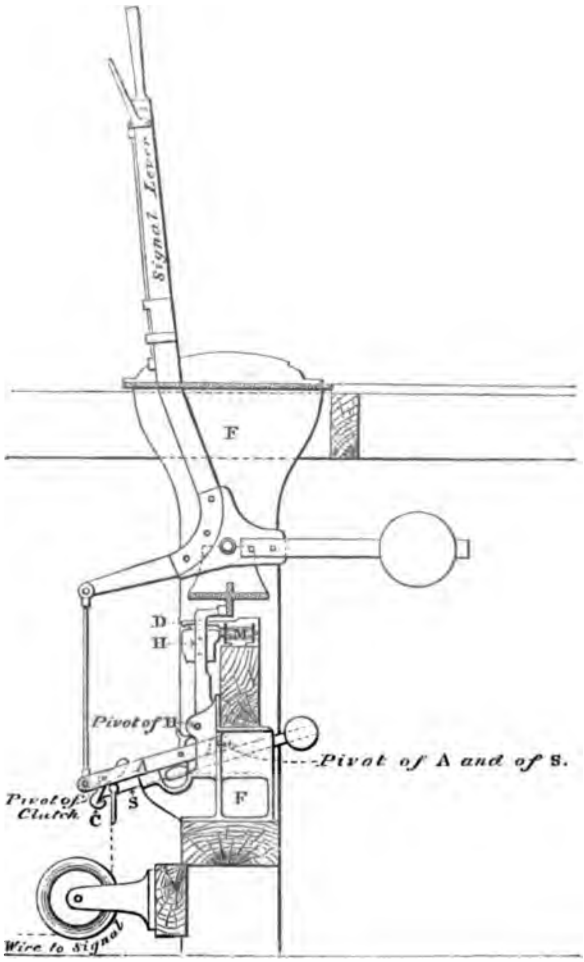


FIG. 162. Electric slot signal apparatus.

is at 'all right,' the signalman in advance can at any moment release the hammer H, which falling on to the clutch, puts the signal at 'danger.'

It will be observed that the advantages of the locking apparatus need not by any means be dispensed with in the apparatus of the electric slot, and the main lever shown in the sketch may be supposed to be one of a number of signal levers placed in an ordinary locking frame and interlocked with the point levers. It in fact carries out by means of an electric current—which can be conveyed to any distance by means of an ordinary telegraph wire—the principle of the mechanical slot (which, owing to the difficulties involved in the use of long connecting rods or wires, cannot be applied to signal boxes further distant than about 1,000 or 1,200 yards), in so far that neither of two signalmen can lower the signal to allow a train to proceed without the active consent of the other, but either of the two can at any moment put the signal to 'danger,' and can keep it there.

Means have also been proposed, and have in places been adopted, for interlocking the point and signal levers with the levers or keys which work the electric signals. These are very promising contrivances, and at present may be said to be on their trial.

A point on which some difference of opinion exists among railway managers is the question whether or not a telegraph-speaking instrument should form part of the furniture of a signal box. It is said that a speaking instrument is apt to induce a want of stringency in working the block system, as a signalman, if a train does not arrive when he expects it, will begin to talk to the next signalman as to the reason of its non-arrival, and may produce some accident, from want of complete knowledge of what

is happening elsewhere; whereas all that a signalman should do in case of delay in the arrival of a train is to keep the line behind him blocked, and that it is an error to give him the power to modify the working of the block system in the slightest degree. Further, it is urged that if speaking instruments are given to the men, they will be used for idle conversation when the men ought to be attending to their duties.

There is no doubt some force in these objections, but not enough I think to outweigh the advantages of having telegraphic speaking communication. The second objection, viz. unauthorised use of the speaking instruments, might be counteracted by mechanical contrivances which would leave a record of the instrument having been used, and render necessary an explanation of its use to the inspector when he visits the signal box.

The first objection, which is more serious, may be partly met by careful regulations as to what is to be done in the case of a break-down, and a strong standing order that in no case is a signalman to relax the block system except under the orders of an authorised inspector. The advantages of speaking instruments are very great, and they have in many cases prevented serious accidents by warning the next signalman of defects observed in the permanent way by an engine-driver, or of something seen to be wrong in the rolling stock and detected by the signalman as a train passed by. In the event of a train on an incline breaking in half, it is in the highest degree useful that there should be means of warning the station at the bottom of the incline, so that those in charge there may be prepared to deal with runaway trucks. In the case, too, of an accident taking place, it is extremely desirable that the particulars of the accident should be forwarded with the least possible delay to headquarters, so

that the necessary steps may at once be taken for the relief of the sufferers, and for clearing the line. Next, there may be defects in the electrical instruments working the block system, and the speaking instrument may then, under a code specially contrived for the purpose, take their place for a short time, in which case, however, every message should be written down by the sender, and both written down and repeated by the recipient. In case of illness also of a signalman, and indeed, in numberless other instances incidental to the traffic of a railway, speaking instruments are extremely useful, and can only be dispensed with at the cost of great inconvenience. Speaking instruments ought therefore, it is believed, to be supplied to signal boxes, but their use should be narrowly watched.

The want of supervision of what goes on in distant signal boxes is no doubt felt by all railway managers, and a tell-tale arrangement has been devised, to record automatically the events of every day. A paper revolving on a time cylinder, driven by the clock of the signal box, is so connected, electrically or mechanically, with the block system instruments, the speaking instruments, the point and signal levers, and by a treadle with the trains passing the signal box, that every movement of signals and of trains is recorded on the paper cylinder at the exact time at which it takes place. A fresh paper can be placed on the cylinder every morning or every week, and the old paper sent to the inspector of the district. By some such means it would be possible to see not only what the signalman did, but also to know whenever any and also which engine-driver ran past a 'danger' signal, without placing on the signalman the responsibility, which is sometimes shirked, of reporting such irregularities.

I could, if time permitted, explain to you many other

contrivances which are in use for, or might be in use for, further carrying out the principles of the block system, but probably I have done quite enough in introducing to you the instruments I have described. You will readily see that the mode of giving the electric signals may be almost infinitely varied, but you will recollect that the cardinal points in all such apparatus are simplicity and trustworthiness under the circumstances of working railway traffic by the ordinary type of railway servants.

Viewing the block system as a whole, it may be safely said that it has the advantage of being perfect in principle in so far that it renders collisions impossible provided it be carried out perfectly; whereas the system of time signalling, even granting that it can be carried into effect without a flaw, gives no absolute security against collisions.

The difference between the two systems, then, is not one of detail, but of kind; and the questions of importance which have to be considered in judging of the applicability of the block system to particular lines and to railways in general, are: (1) can the block system be carried out with sufficient perfection? (2) does it induce other dangers from which other systems are free? and (3) to what extent does it impede the traffic? With respect to the first of these points, it may be stated without fear of contradiction that the block system can be carried out with a nearer approach to perfection than any other known system of signalling. Perfection, however, has not yet been attained, for the simple reason that the system is at present dependent on the intelligence, care, and obedience of signalmen and engine-drivers; and although no words can as a rule be too strong to express the trustworthiness of this valuable class of men, yet human nature is not perfect, and occasionally even the

most tried and steady men may make a mistake in a duty which they thoroughly comprehend, and perhaps have fulfilled without error for years. This objection—viz. its liability to failure from human fallibility—is frequently urged against the block system, but it really is not an objection against that system in particular. It applies to every other known system of signalling, excepting only an automatic arrangement of signals by which trains should signal themselves. A purely automatic system, however, implies absolute reliance on machinery which may get out of order, and which cannot deal with emergencies as can be done by an intelligent and experienced signalman. The great object to be aimed at is to simplify the task which each signalman has to perform, to arrange that every signal made between two signalmen should be checked in order to ensure its having been correctly given and correctly understood, and to simplify the transmission of signals between the signalman and the engine-drivers. Thus, in answer to the first question, it may be stated that the electric telegraph supplies all that is required to make the block system sufficiently perfect for railway signalling, though as yet perfection has not been obtained in the means by which the block system is carried out.

The second suggestion, that the block system introduces new dangers, which is the heaviest charge against the system, is endorsed by some few railway anthorities, brought up under the old system of time signalling. They accuse the block system of inducing among engine-drivers a feeling of security, which makes them run carelessly from signal station to signal station, without keeping so sharp a look-out for chance obstructions as they formerly did ; and they assert that, consequently, the general level of care and intelligence in engine-drivers is

being gradually lowered. It is true that engine-drivers proceed at a higher speed in thick weather under the protection of the block system than formerly, but the increased safety of the system justifies them in so doing. It must be borne in mind that engine-drivers are generally the first to suffer in a collision, and that there is no reason to suppose that they are more careless of their lives and limbs than other folks. If the block system has made such men feel a security which they did not feel before, it is fair to assume that it must be because it has been found to be safe, compared with other systems, by the very men who are most interested in its merits and demerits and who are well qualified to form a sound opinion thereon.

Engine-drivers are fully aware of the danger of chance obstructions, or defects in the road, and it is probably a mistake to suppose that they do not now-a-days keep as good a look-out as ever they did. But, as this matter is one which is much discussed, it is as well to try to understand what safeguard a good look-out gives, when compared with efficient signalling, and what are the chances of attaining any safety worthy of the name under the modern conditions of railway traffic by the best look-out, combined with imperfect signalling.

A train travelling at the rate of a mile a minute can, with ordinary break power, pull up in half a mile, and on a clear day and on a straight line of railway, the engine-driver may see for about a mile in front of him. If he sees a vehicle a mile off, he must, if he trust merely to his vision, at once make up his mind whether it is on his own line or not, which is not very easy, and he must act immediately on his decision. If the line be curved, it is extremely difficult, till one gets near to a train, to tell on which line of rails it is standing; while, further,

on the clearest days an engine-driver has to contend with the obstruction of view caused by steam from his own or other engines. If the above is the case on a clear day, the chances of attaining safety by a good look-out in thick weather, on a dark night, or in a tunnel half full of smoke, are very much less. The fact really is, that the safe conduct of railway traffic depends, and must depend, on good signalling, which will prevent trains from overtaking one another, and that any systematic reliance on a good look-out to make up for the shortcomings of signalling would, with the traffic which our lines now carry, be ruinous. The look-out for signals of all sorts must be of course the best, and engine-drivers must be prepared for unexpected signals in cases of exceptional difficulty, such as, for instance, a defect being suddenly discovered by plate-layers in the permanent way, in which case it should be remembered that reliance ought not to be placed on an engine-driver seeing a small flag or a dim hand lamp, but fog signals ought to be freely used as well. But these instances should be quite exceptional, as in ninety-nine cases out of a hundred, when the progress of a train has to be unexpectedly arrested, owing to the breakdown or delay of a preceding train, it will be effected under the absolute block system by the ordinary standing signals, at places at which signals are as a rule exhibited, and this is not necessarily the case with time signalling, or with the permissive block system.

The trains which use a line of rails in a day at the present time on the main lines of traffic are, in many cases, double or treble the number which used the same rails in the same time twenty-five years ago; and though, perhaps, the speed of fast passenger trains has not much increased of late, the variety of trains is much greater.

On such a line as the London and North Western, between London and Rugby, there are at the present time sixty-four through down trains a day, all of which travel for part of the distance over one line of way. These trains include among them express passenger trains, stopping at no station between London and Rugby, slow passenger trains stopping at nearly all stations, express goods trains, slow pick-up goods trains stopping at all stations, mineral trains, and parcels trains. On portions of the Midland Railway there are nearly twice as many similar trains on each line of way. Such an amount and variety of traffic could not have been carried on under the time system with anything approaching to the degree of safety which is attained by the block system. And it is probably the fact that, if the use of the block system were to be suddenly suspended, the carrying power of at least the busy parts of our railway system would be diminished to an extent for which few people are prepared.

The last consideration is, whether or no the block system is of necessity so restrictive as to impair the carrying power of the lines. It must be admitted that any system of signalling which could be devised must act at times as an impediment to a free and unrestricted use of a railway, for rules cannot be at once stringent and elastic. It is of more consequence that the rules regulating railway traffic should be stringent, so long as they are sound, than that now and then a train should be delayed, if the delay does not lead to a collision. But the question is, Does the block system, when properly carried out, of necessity impede the conduct of traffic? On a fair consideration of the whole question, the answer must be in the negative. The Metropolitan Railway Company work trains at the rate of 18 per hour on each

line of rails, or with average intervals of $3\frac{1}{3}$ minutes between trains, and the minimum interval is considerably less. The District Railway Company and the South Eastern Railway Company on their Charing Cross Railway have about the same number of trains per hour on a line of rails; and many other similar instances could be given. It seems difficult to understand how a system which allows of such an enormous amount of traffic being worked safely on a line of rails, can be considered restrictive compared with any other known system, but it can easily be understood that the application of the block system to deal with so great a number of trains requires some considerable forethought and prearrangement. On the lines to which allusion has been made, the length of the district under the control of each signalman is, in many instances, less than a quarter of a mile, and it is to be remembered that there is no advantage under the block system, so far as safety is concerned, and every disadvantage so far as freedom of traffic is concerned, in making the districts needlessly long. In determining the length of the districts the points to be considered are, how much traffic has to be passed over a line in a given time, and in how short a space can a train, travelling at the highest speed permitted on the part of the railway in question, be with certainty and with a proper regard to economy pulled up. Economy is mentioned because there may be means adopted for pulling up a train in a very short space of time in cases of emergencies, which may be such as produce serious strains and so much wear and tear on the rolling stock or permanent way as to be unsuitable for ordinary application. Where heavy trains habitually travel at 50 or 60 miles an hour, the distance between the signalling stations should be much greater than where the speed is lower. At the

present time, even under the most unfavourable circumstances, there ought to be no difficulty in pulling up a fully loaded long train with continuous breaks running on an ordinary line at full speed in 800 yards; if to this distance the length of a long train, say 200 yards, be added, we get the minimum distance of 1,000 yards required between trains travelling on a main line of rails, where the speed is practically unlimited, and the time taken by quick trains to traverse this distance would be about $\frac{2}{3}$ of a minute.

Trains cannot, however, follow one another so closely as this, as a train will be checked by the distant signal at one station, unless the next block is clear; but making allowance for this it seems that, so far as time alone is concerned, about 50 quick trains per hour might be passed by the block system over such a line, with proper intervals between the signalling stations, provided no other circumstances but the signalling had to be considered; and this number is very far in excess of what is required for any main line. Where the speed is low, as, for instance, on the Metropolitan Railways, and on the lines approaching London, or other large towns, the lengths of the blocks may be greatly reduced. Further, if it be desirable, there may be intermediate block signalling stations to be used for the slow trains and not for the quick trains, so that the length of the block district may be proportioned to the speed of the trains, and the distances between the signalling stations for slow traffic may approach to the lengths on the Metropolitan Railways. Thus it may with truth be asserted that if a railway be properly divided into block districts, proportioned to the speed and to the greatest number of trains to be accommodated, the block system is capable of dealing with any amount of traffic which, for other

reasons, is practicable. But it is no doubt the fact that where a railway is not properly divided, or where an exceptionally large amount of traffic is, for a day or two, thrown on a district which is laid out for a much smaller amount of traffic, the result under the block system may be more or less delay. This is, however, a small matter, compared with the safety which the system gives, and it can always be rectified either by dividing the line properly, or, in exceptional cases, by temporary arrangements, such for instance as attaching two or more trains together and allowing them to proceed in company.

It is sometimes said to be unreasonable that if a train is shunting across the line at station A, occupying in the operation perhaps a quarter of a minute in so doing, the line should be required to be blocked back to B, which may be three or four miles off; but the answer to this objection is (1) that if it is inconvenient it is at least safe, and (2) that if the inconvenience is severely felt, it must be because the traffic of the line is heavy, and the danger therefore considerable, and (3) that the inconvenience can be remedied by inserting an intermediate signalling station.

The question, after all, resolves itself very much into a matter of expense, and it must be admitted that the expense of carrying out the block system is very heavy, entailing, in addition to first cost, the expense of constantly employing the requisite number of extra signalmen, and the annual wear and tear of the apparatus and wires. But the cost of efficient signalling is a remunerative expenditure, both in developing the capabilities of a railway and in preventing those accidents which are not only deplorable to all those concerned in them, but are extremely costly to shareholders in railway companies. The additional ex-

pense, therefore (even neglecting all but pecuniary considerations), is not sufficient to constitute a valid objection against this most valuable system.

Granting, however, all that has been said of its advantages, the block system, as at present ordinarily carried out, cannot be said to be perfect, for there are undoubtedly two important wants which, with the usual appliances, are not yet completely satisfied. First, there is no security that the position of the out-door signal exhibited to an engine-driver agrees with the orders sent by electricity. Secondly, a mistake can be made in sending or acting on the electric signal—for it is possible, under existing circumstances, that a signalman may signal a line as clear when he has not received the 'all clear' signal from the signal station in advance, and it is at present possible to give an electric signal which is not in accordance with the position of his points or out-door signals. The two imperfections which I have described will, I think, before long be cured.[1]

The first want will probably be supplied by the electric slot, or some similar contrivance, and I am in hopes that we shall see the second requirement supplied by an electric apparatus connected with, and interlocked with, the interlocking apparatus and switch-locking bars. Such an extension, or intermarriage, of the two systems will both prevent the possibility of a signalman sending a wrong electric signal, and will also ensure that the electric signals are always in accordance with the out-door signals and with the position of the points.

The subject of the block system is, perhaps, rather

[1] Since these lectures were delivered, the improvements desired have been supplied by an arrangement by which the electric orders control the interlocking and the positions of the signal and point levers control the electric messages.

the business of the traffic manager than of the engineer. I have, however, thought it well to bring it before you, because not only may you be some day in the position of a railway manager of some state line, but also because, without precisely following all the details I have referred to, you may find the general principles of the system very serviceable in the class of railway work you may be called upon to perform. A cheap but sufficient single wire telegraph may enable you, on the block system, to run very frequent trains over a single line of way. The power of thus running very frequent trains may, if you can get sufficient locomotives, enable you to run a large number of light trains instead of a smaller number of heavier trains. The power of running light trains may, by enabling you to adopt much steeper ruling gradients—permit you to make an easier line, and therefore to open a line in much less time. Thus the application of the block system may enable you to construct not only a cheaper, but also a more quickly made line, which last matter of speed of construction is for military purposes most important.

I will now, in the short time that remains to me, try to put before you such views as have occurred to me as of special importance in the application of railways for temporary purposes; adverting by the way to a few practical expedients for dealing with exceptional cases of difficulties which may be encountered.

I am well aware that you must be much more conversant than I am with the special requirements of a military line, and also that you have many suggestions for satisfying those requirements in your text-books and in your course of study. Still, I shall attempt to run rapidly over the ground covered by my previous lectures,

and to point out, from my point of view—*i.e.* from the point of view of a civil engineer—what are the chief matters of ordinary railway engineering practice that will be of service to you in constructing railways rapidly, and under difficulties as to the supply of materials. The paramount importance of rapidity of construction is the only essential element of difference between railways for military and civil purposes.

To begin, then, as I began in my first lecture, with laying out the line and the ruling gradient.

If rapidity of construction is of very great importance, I should say, Do not hesitate to adopt very steep gradients in order to have a line following the surface of the ground, and you will find that you can get this in almost all countries where a temporary railway is likely to be thought of. A suitable ordinary locomotive engine of about 30 tons weight, with all its wheels coupled, can, by itself, ascend slowly a gradient of 1 in 10, and can drag about 50 tons weight up a gradient of 1 in 30. It is sometimes said that such a locomotive will by itself ascend a gradient of 1 in 7; but I prefer to take the gradient of 1 in 10 as more to be relied on. If it becomes necessary to adopt an extremely steep gradient on some part of a line, a great deal of traffic may, with proper arrangements, be carried on, by stopping the trains at the foot of the incline, breaking them up and taking up two or three trucks at a time. This, of course, requires a siding at the top of the incline to receive each batch of trucks, or perhaps some arrangement of loop lines for the same purpose. On any such steep inclines where the up-hill trains have to be broken up, it will, in many cases, be found useful to have a double line of railway, in order that the down-hill traffic may pass

uninterrupted, while the other trains are being taken up the incline in detachments.

Many arrangements for working extremely steep inclines will no doubt occur to you, bearing in mind that even a single locomotive is a very powerful machine. A suggestion of a method of hauling trucks up a steep incline is given in fig. 163.

The incline on which the engine runs is say 1 in 10, which we will assume to be the steepest incline up which the engine can be relied on to return by its own power. Then to pull the two comparatively light trucks of say 10 tons up the very steep incline of 1 in 2, we have the power of the locomotive in addition to its own weight acting down the incline of 1 in 10. If the trucks have to be dragged up an incline of 1 in 10 instead of 1 in 2, the same arrangement would greatly increase the possible load, as it would enable a locomotive weighing 30 tons to drag a weight of 50 tons; and this plan is preferable to the former, as it would allow of heavy traffic being worked in either direction.

Again, if there are any tolerably good workshops available, it ought to be possible to convert a locomotive engine into a stationary winding engine, by blocking it, either temporarily or permanently, off its wheels, and attaching a short drum on to one of the driving wheels, round which drum a rope for hauling up the trucks could be led, with two or three turns, as round the drum of a steam winch. In this case the rope must be fleeted from time to time and coiled alongside the engine, but by passing the rope round two drums it can be made to wind in without fleeting, which is always an inconvenient process.

For a similar purpose, Mr. Handyside's arrangement deserves attention. This consists of a steam winch or crab

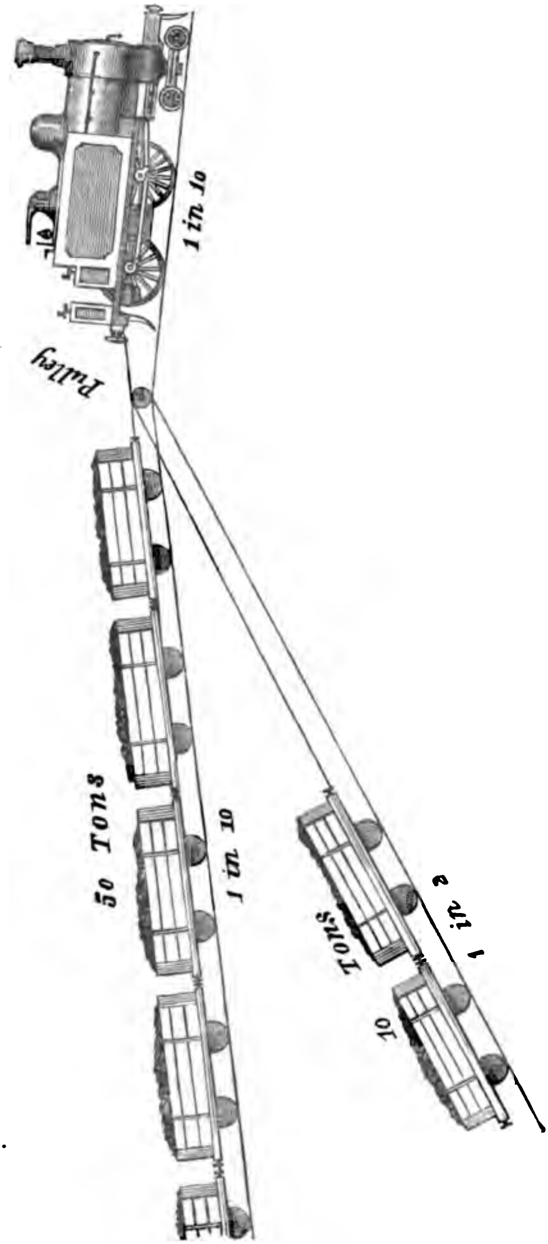


FIG. 163. Hauling trucks up a steep incline.

on the tail end of the engine, by which the trucks are hauled up to the engine by a steel wire rope coiled round the drum of the crab. Both engine and train are provided with clip breaks, by which, when going up an incline, they are prevented from running backward. When a steep incline has to be ascended the trucks are at first left standing still, secured from running back by their clip break, and the engine runs on in front to the extent of the length of the rope. Then the engine stands still, secured by its clip break, and by means of the steam crab and rope the engine proceeds to haul the trucks up after it, and the process is continued until all the train has been dragged up the incline. As the crab may be made of almost any amount of tractive power with slow speed, the only limit to the gradient which can be surmounted is the power of the locomotive to go up-hill by itself, which, as I have said, limits us to about 1 in 10.

These expedients might, no doubt, be useful for dealing with exceptionally steep places met with in the construction of a temporary railway; but, as I have said, it is seldom that inclines will be of necessity so steep as to be unworkable by a locomotive. As bearing on this subject it is well to recollect examples of steep inclines in use for very heavy traffic, and worked entirely by locomotives. Thus we have the Oldham incline, with a gradient of 1 in 27; the Folkestone Harbour incline of 1 in 30; the Navigation incline on the Taff Vale of 1 in 29; the Mauritius railways, on which there are very long inclines of 1 in 27; the Chilian railways, with inclines of 1 in 20, 1 in 21, 1 in 24, 1 in 30; and many other examples might be mentioned of even steeper inclines which have been and are worked successfully by locomotives.

While adverting to this subject, I ought not to omit to notice the railway which was constructed on

what is called, from its inventor's name, the 'Fell' system over the Mont Cenis pass. That railway was 48 miles in length, and ascended to a height of 6,658 feet above the sea, rising about 5,200 feet above its Italian terminus in 17 miles. The line was laid with a central rail, and was worked by special locomotives for a considerable length of time. The ruling gradient was 1 in 12, and there were about 30 miles of gradients, varying from 1 in 12 to 1 in 15. The gauge was a mètre, and the sharpest curves were 2 chains radius. The necessary adhesion of the engine wheels was obtained partly by the weight of the engine, but chiefly by horizontal wheels, as shown in fig. 164, which were driven by the engine and pressed against the central rail by powerful springs. As it turned out, there were many practical difficulties in the new system, and there was much to be learnt at first in the construction of the new locomotive; so that it is not surprising that the Mont Cenis railway, the first of its kind, and used in a locality where it was exposed to great disadvantages, was not a financial success. The system has undoubted merits for exceptionally steep gradients, and one of its advantages is in the large amount of break power which can be readily applied to the central rail by horizontal wheels on the carriages and vans, pressed against the rails in the same manner as in the case of the engine wheels. I rode on the engine down from the summit of the pass to Susa, descending the steep inclines, and passing round the sharp curves, which I have mentioned, for many miles. The sensation of de-

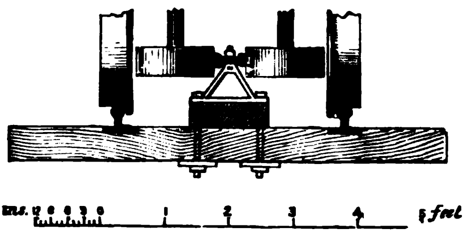


FIG. 164.

scending such an incline along the brink of precipices with a tolerably heavy train behind one was at first somewhat alarming, but one soon felt what entire control the break wheels on the central rail gave to the breaksman, and what a safeguard the central rail was against the train leaving the rails. If ever the Fell system were worked again, I should like to see the experiment tried of discarding the idea of utilising the adhesion due to the weight, and applying the engine power altogether to the horizontal wheels whenever the horizontal wheels have to be used. Much of the difficulty which was experienced with the Mont Cenis engine was probably due to endeavouring to employ in one locomotive at the same time the two systems of procuring adhesion. I do not suppose that the Fell system is likely to be suitable for temporary lines, except under very special circumstances where the severity of the gradients is known beforehand, and where there is time to prepare the special locomotives and special permanent way. There are also certain practical difficulties attending it which have to be overcome before the Fell system can be said to be a mechanical success. It is, however, well worthy of consideration, whether its essential merits are not sufficiently great to call for further experiment.

Another example of a railway designed for a special situation and for special traffic is that which has been laid on the Rigi Mountain in Switzerland. The arrangement there adopted for motive power is a locomotive turning a toothed wheel, which engages with the teeth of a continuous rack, laid between the rails which support the weights on the wheels of the engine and carriages. The gradients vary from 1 in 4 to 1 in 6, and there are about 3 miles of those rates of inclination. I believe that the Rigi Railway has been worked for 6 or 7 years, with a

heavy summer traffic of passengers, without any accident of importance.

Bearing in mind the views which I have expressed as to steep gradients, I would say that, if you have to construct railways for temporary purposes—particularly in the case of railways made to replace portions of a destroyed line, such as where a viaduct or tunnel has been blown up—do not expend much time, in the first instance, in repairing such large works, but go boldly to work with a new line over the top of the hill or down into the valley. With plenty of hands a surface line is soon got ready for the rails, and a large amount of traffic may be worked with it. In the meantime the more tedious work of repairing the partly destroyed tunnel or viaduct may, if desired, be proceeded with.

The contractor's lines about large dock or railway works are instances of steep gradients usefully worked. I remember hearing Mr. Harrison, the engineer to the North Eastern Railway Company, describe how lately, on a new line from York to Selby, where a ruling gradient of 1 in 240 had been adopted for the permanent line, involving considerable cuttings and embankments, the contractor had for his own purposes laid and used for two years a surface line with very steep but short gradients, over which his trains ran safely at 20 miles an hour, taking advantage of the velocity gained in descending the short and steep inclines to enable the engine to surmount the up-hill gradients of similar character. The extent to which the momentum may be thus usefully employed is a matter which is easily reducible to figures.

While proceeding with a surface line it will in many cases be desirable to so lay it out that its worst features are concentrated in a few places, where its inconveniences

as a surface line may, if desired, be afterwards obviated by works more slowly constructed.

Where temporary lines are laid across a valley liable to be flooded, if they cannot be raised out of reach of the floods, care should be taken that the line does not form an obstruction to flood waters, and that the rails and timbers should be secured from being swept away. If these precautions are taken, and if, in positions where scour may be anticipated, the line be pitched with stone or similarly protected, the water may be allowed to run over the line without danger. A railway may be worked sufficiently well with water standing on the rails to a moderate depth. Indeed, though such a state of things is eminently undesirable, an engine can work through water 3 feet deep for a short distance, since, with the steam in the boiler, the engine will continue to go on some little time after the fire has been extinguished. In such a case, and indeed in all cases of an engine travelling through water, care must be taken not to permit the water to rush into the fire, as the engineman may be seriously hurt by the sudden formation of steam in the boiler.

I may remark that some of the most important temporary lines laid by civil engineers have been in India, where, in the case of viaducts and embankments being swept away by sudden floods, deviation lines have been rapidly constructed across the surface of the ground and over the beds of the streams as soon as the waters had subsided.

So much for laying out temporary railways. With regard to works of construction on such lines, I may say that except with regard to the durability of materials, which consideration may be neglected, greater care is required in the design and construction of temporary works than in the case of permanent works; for not only are such works,

as a rule, exposed very quickly to their full duty of resistance to loads and other strains, but further the mere fact of their being temporary is liable to induce a disposition in engineers to be content with a smaller factor of safety than would be adopted for permanent works.

In earthwork it is most essential to provide amply for the drainage. In constructing a permanent railway, if very wet weather comes on, or a tendency to slip is observed, the progress of the earthwork is stopped; but in a temporary line you may not be able to afford the time to do this, and you may be obliged to continue tipping an embankment with wet material. In such a case it would have been most valuable to have had very full provision made for drainage; but when the wet weather comes, it will probably be too late to do this thoroughly, as the base of the embankment, which is the critical part, may be already formed. I would advise, therefore, that in all temporary earthworks where time is of importance, excessive precautions in providing for the drainage should be taken in the first instance.

A slip that stops the traffic of a temporary line which has been depended on for military operations, may possibly produce results so injurious that it would have been better if the line had not been thought of.

If masonry or brickwork is used, it should be remembered that most mortar when it is green does not possess half the strength which it has after it has had time to set; it is therefore the more important that works should be well designed. If the centres are not struck too soon, an arch built of good bricks and mortar will stand, even though badly designed; but an arch with green mortar requires to be carefully equilibrated. These considerations will remind you of the great value of Roman or Portland cement for all temporary works. Not only does the use

of cement avoid the dangers of green mortar, but it also enables you to economise in the thickness of brickwork or masonry, in consequence of the tensile strength which good cement affords almost immediately after it has been used.

It may often happen that by taking dressed stone or bricks from buildings the piers of bridges may be quickly built, and thus if timber is scarce it may be spared for the superstructure or for the permanent way. But such masonry works should, as regards their strength, be looked upon rather in the light of dry walling, and be designed accordingly, unless quick-setting mortar or cement be procurable.

For flood openings I should advise you to use, whereever it is possible, gaps in embankments with pitched slopes on each side, spanned by short bridges, in preference to the construction of culverts, whether of masonry or timber.

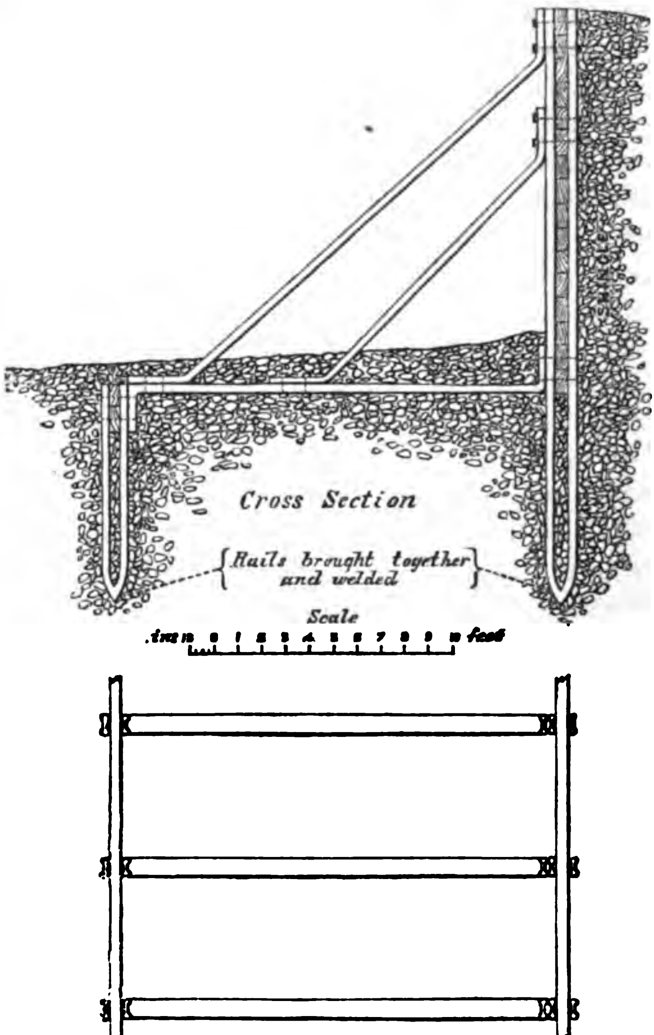
Where the end of a viaduct joins an embankment, especially if this is liable to settle, I call your attention to the arrangement shown in fig. 17, p. 51, which is adopted in most of the lofty viaducts in Cornwall. The end of the viaduct is formed somewhat like a drawbridge, with trussed parapets resting on a timber platform on the top of the embankment slope. In the case of any slight settlement of the bank, the end of the viaduct sinks with it, and thus the permanent way is not disturbed, and there is no serious shock to the train in running on to the viaduct.

I will not refer to the repairs of bridges, as this subject is fully dealt with in your course of study here. I would only remind you of the concentration of weight which has to be guarded against in railway structures, and of the strain due to the unequal loading of a bridge or viaduct which is used to carry any railway vehicle,

particularly a locomotive. If a bridge be frail and you have to pass a train over it, do not attempt to send a locomotive over it until you have got all your trucks across; and, when the attempt is made, endeavour to spread the weight by every device in your power, such as adding longitudinal timbers, bolting rails together, or any rough system of trussing. Empty the boiler, water-tank, and coal-box, and if the load on any pair of wheels is more than others, equalise it on all the wheels if possible by wedging up the springs. Make sure that the permanent way has no drops in it, or defects that will produce jars to the structure at the critical time. In some cases it may perhaps be useful to load adjacent spans of the structure for the purpose of reducing the unbalanced effect of the travelling load, and of counteracting the strains due to it.

In constructing a timber viaduct or superstructure, if suitable timber is plentiful and ironwork for connecting bolts is scarce, a good load of ballast may with advantage be laid on the planking, the weight of which relieves the vibration of the structure, keeps the various parts of the framework in close contact, and alleviates the sudden jars being brought on them by the rapidly applied load of a passing train.

I would direct your attention to the great value of rails for the purpose of repairing bridges or viaducts; I mean for constructing rapidly a stiff and strong iron frame. The holes in the rails, the fish-plates, and bolts furnish a ready means for attaching the rails together, and the rails can be pretty easily bent to any required form if heated in a fire. I have in my mind at the present time a pier in the sea built mainly of old rails, and also several other structures which have been cheaply and quickly made in this way. The fig. 165 shows a groin on the sea-shore which I recently inspected and measured, of



Plan

FIG. 165.

which everything but the planking is made of old railway metals.

I come next to the construction of the actual railway. In looking at a contractor's temporary railway, one of the

first things that strikes an observer is how badly, or rather how apparently badly, a line may be laid, and yet be sufficient for the conveyance of a vast quantity of traffic at a slow speed. It is certainly remarkable how the wheels of the engines and vehicles manage to remain on the rails of many temporary lines. The reasons here are no doubt, firstly, tolerable accuracy of gauge of both rails and wheels; secondly, a short wheel base for all vehicles using roughly laid lines; thirdly, a good subdivision of the weights over a large number of wheels; fourthly, the avoidance of greatly concentrated weights; and fifthly, a low rate of speed.

If these conditions are complied with, much may be done with a railroad of a most rudimentary description, and I should like to say a word of caution against despairing of constructing a useful railroad or tramroad under even most unpromising circumstances. Very light rails can be made serviceable if they are properly supported by sleepers, and there can be no doubt that *cæteris paribus* support is better given to light rails by longitudinal sleepers than by cross sleepers. I should not, indeed, wish to suggest that for all or even many temporary lines the longitudinal system is to be adopted, because it certainly is not so handy as the cross sleeper system for improvised work, either in first construction or in maintenance. In a cross sleeper road the sleepers may be of any length or scantling, provided that there are enough of them, and that some are long enough to maintain the gauge at suitable intervals. Timber for cross sleepers can be generally obtained pretty easily, and may, at a very small expenditure of labour in cutting a seating for the rail, be quickly got ready for service. In the longitudinal system, while longer and larger, and therefore scarcer, timber is wanted, much more uniformity of sec-

tion is also required, and further, one side at least of the timber must for its whole length be specially prepared to receive the rail. When, however, fit timber for longitudinals is accessible, it will facilitate the use of a light rail. Indeed, a very passable temporary tramroad may be made with longitudinal timbers only, without rails, or with the edge and tread of the longitudinal, fortified by an iron plate. I may observe that the joists and roofs of houses would supply very fair materials for such a light tram-road.

For temporary railroads which have to be worked by horses, the sleepers may most advantageously be laid touching one another, as it is of high importance that a horse should have good foothold and not step one moment on a sleeper and the next moment to be over his fetlocks in soft soil or mud. It is also to be remembered that in working a line by horses it is extremely difficult to maintain good side drainage, except with a continuous platform of sleepers. The horses tread continually in the same place, and not only wear away the surface of the soil, but also convert it into the form of more or less impervious mud, performing indeed the operation of puddling. Thus for such lines, as indeed for temporary roads to be used for carts over soft soil, there is nothing so serviceable as what is known as the corduroy road, which is a platform of cross sleepers covered over where the horses tread with a layer of fine gravel or other suitable material attainable. Where such an arrangement is adopted, it is obvious that an exceedingly light rail may be used, and it will probably be found in many cases to be true economy to be extravagant in sleepers, and to save in the weight of the rails.

I need scarcely say that in such temporary lines as these to which I am alluding I discard the idea of ballast.

If you can get it so much the better, but do not think it a necessity. Many capital permanent lines are at work without ballast, and for temporary lines it may be said to be frequently an impossible luxury. But remember that the use of ballast is very valuable for the purpose of drainage, and therefore, if you have no ballast, you must pay the more attention to the side drainage of the line. I have already pointed out that something may be done in this way by rounding off or sloping the tops of earthworks transversely at formation level, so that when the earth is consolidated the water may run off the surface, and not soak inwards. This is, however, only a palliative, and deep side drains are truly essential parts of a good line, whether temporary or permanent. In military lines you may be unable to procure ballast; but you can generally get men enough to dig good drains, and there are not many places in which you cannot get an outfall for the side ditches.

It may be necessary for you to construct a temporary railway or tramroad either for horse or locomotive traction in trenches for siege works, and in that case you may have a difficulty in getting an outfall by gravitation for the side ditches. In such cases I would urge that even at a considerable expenditure of labour the side ditches should be kept clear by pumping or some other artificial mode, and suitable lengths of the ditches should for this purpose terminate in sumps from which the water can be raised. For this purpose horse power or manual labour may be employed, or in many cases it may be convenient to use steam pumps. I feel quite sure that where you want to keep a railway or tramroad in working order, there are but few cases where labour can be more usefully employed than in keeping side ditches dry to which a natural outfall cannot be given.

With regard to the rails to be used on temporary lines I would say that no section is to be despised, provided you can get enough cross sleepers to support it. If you cannot get timber for sleepers, try stone sleepers, on which our early railways were laid for years. I heard some time ago a story (for the truth of which I will not vouch) of an engineer in charge of the construction of a temporary railway abroad, the rails for which had been sent him from England, whose life was a burden to him because he could not open the line without the fish-plates which had (for some wise purpose) been ordered to be sent to him from another quarter of the globe. I can imagine that the engineer may have wished for the fish-plates, and that he may have had his own opinion of the management which sent rails from one country and fish-plates from another, but there ought not, I think, to have been much difficulty in dispensing with fish-plates altogether, seeing that up to 1845 they were unknown, and that all railways were worked without them. Of course, in the absence of fish-plates, one must discard the idea of a suspended joint, that is to say, of placing the joint between the ends of rails intermediate between two sleepers. Resort must, in such a case, be had to the old system of placing a sleeper under the joint, and every endeavour must be made to hold the ends of the rails firmly down by putting plenty of fastenings near the ends.

The most convenient form of rails for temporary lines is no doubt the single-headed, or Vignoles rail. The weight and strength of it ought to depend, as I have said in one of my former lectures, (1) on the greatest concentrated weight on any pair of wheels; (2) on the system of sleepers, and, if cross sleepers are used, on the distance apart at which those sleepers will be placed. Conversely, as I have remarked, the distance apart of the

cross sleepers must depend on the section of rail which may be procurable. This question of sleepers will be also influenced by the consideration whether the line is to be worked partly or entirely by horses.

For short distances railway wheels can run on their flanges, or partly on their flanges and partly on their treads. Thus in extreme cases you could run vehicles over flat plates and on double-headed rails laid sideways, having in the case of flat plates something such as timber at the side to guide the wheels. I of course only suggest such an expedient for cases of a short gap in a railway, where time will not allow of any better sort of roadway being improvised. It is well to bear in mind that railway vehicles are made extremely strong in their wheels, axles, springs, and under-frames, and will stand a great deal of rough treatment, such as running over badly laid rails, over flat plates, or even over timbers without rails or plates.

In order to straighten rails or to curve them, a usual plan is for the rail to be laid on its side with the ends of the rails only supported, while men stand at the unsupported centre and jump or move their bodies up and down. This mode is only efficacious where a simple and not a compound curvature has to be cured or given. If the rails are twisted (as I see Sir Garnet Wolseley suggests should be done to the rails of a railway which is to be rendered inefficient), I don't well see any rough and ready appliance to remedy the mischief in any reasonable time. Something might perhaps be done by nicking and breaking the twisted rails, which can be pretty quickly done, and by then using any straight parts to form a rough tram-road. This would be a possible plan, more particularly in the case of flat-bottomed rails.

With respect to points and crossings, you would of

course for improvised lines use the contractor's form of these appliances. You will remember that, as I described in my third lecture, this form of points and crossings requires no rails of special form or length. The points are made by pivoting two rails of the ordinary description. The crossing is made by passing one rail over the other rail, and pivoting the upper rail at the place of crossing so that the movable rail can be shifted when vehicles travel over the lower rail. If the rail which you have to use for this purpose is of a Vignoles section, the movable rails for both points and crossings will rest well on their flat base, but if the section be that of a double-headed rail, you had better make provision for the chairs sliding with the movable rails, or you may imbed the rail in a balk of timber or flitch it with timber. At all such places the speed must be slow. It is well to remember that you can always better afford a low rate of speed than the risk of trains running off the line.

The arrangements of fixed signals apply as much to temporary as to permanent lines with regard to interlocking. I would say, do not suppose that because a line is only to be used for six weeks, or for six months, you can on that account afford to despise precaution.

Some very simple expedients will go a great way to obtaining the advantage of the interlocking principle. In the rough and ready arrangements that must be adopted in a temporary railway, a concentration of point levers and signal levers in a locking frame would very likely not be attempted, but this is in some respects the greater reason for using some sort of interlocking.

Fig. 166 shows a simple arrangement suitable for a single junction which may be amplified in ways that will suggest themselves as occasion arises. In the single line of way, A B, there is a branch siding C D. The points

of this siding are facing points to traffic coming from A towards B, and they are protected by a signal, S. The interlocking we require is that the signal S cannot be lowered to 'all right' unless the points are right for the train to pass by the line, A B, and not by the line, A C; also that if the signal is lowered to 'all right' for the line A B, the points cannot be moved so as to turn a train

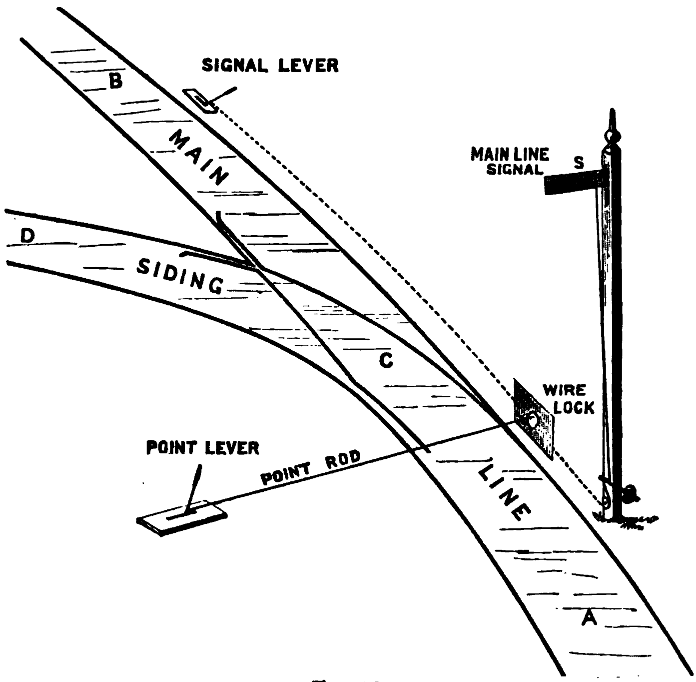


FIG. 166.

coming from A into the siding C D, but must remain locked in the position which is right for the main line, A B.

This may readily and inexpensively be effected by the use of a flat plate with a hole in it, which forms part of the signal-wire, and which slides opposite to a continuation of the point rod. When the points are set right for

the main line, the point rod is withdrawn from the hole in the flat plate, and the signal can then be lowered, but the act of lowering the signal removes the hole in the plate from opposite to the point rod, and the point rod cannot therefore then be moved, because the solid part of the plate will be opposite to the prolongation of the point rod. Amplifications of this principle will suggest themselves to you, and they can be easily improvised without the help even of a fitter's shop.

I come next to the working of the line. And, with regard to this, though I have made no reference to station appliances in my lectures, I ought here to remind you that in preparing any temporary line, especially if it be a single line and one with steep gradients, it is most important to provide frequent watering places for the locomotives: indeed storage for one or two charges should be provided at every four or five miles on a temporary line. The roughest arrangements, mere wooden troughs from a row of casks, will suffice; but a waterless locomotive is helpless, and must put out its fire and remain torpid, till water is brought to it or it is taken to water.

With regard to the block system, I have already urged its applicability to temporary lines. You must have a telegraph wire for other purposes, and the habits of discipline to which military instrument-men would be accustomed would ensure that the block system could be worked by them, if need be, on the same wire as the speaking telegraph.

For working a line as a single line, either in the absence of the electric telegraph or even with its help, the train-staff system should be adopted; but if the length of single line be very short it may be worked by a pilot-guard, that is to say, by telling off a man specially for the purpose, and not allowing any train to start unless that man

is on the engine. The pilot guard should always be distinguished by a special dress.

The train-staff system, which perhaps requires a detailed description, is as follows :—The railway is divided into districts, A to B, B to C, C to D, and so on, and a staff like a policeman's truncheon is set apart as belonging to each district. To avoid confusion, the staffs are usually dissimilarly shaped, or made of dissimilar materials, and the staff of one district must on no account be taken off that district. Under the 'train-staff' system no engine-driver may start from any station forming the terminus of a district without having actually in his possession the staff belonging to that district, and as the staff cannot be in two places at once, it is impossible that a collision can take place between two engines.

Supposing that a train is travelling from A to D, the driver of the train will receive the proper staff at A, give it up to the station-master at B, receive another staff at B, give that up at C, receive another staff at C, and give that up at D. As soon as the station-master at B, C, or D, receives the staff from the engine-driver he may allow a train to go in the opposite direction by giving the staff to the driver of the train wishing to go in that direction. The arrangement if rigidly adhered to manifestly ensures absolute safety from collision, but it is inconvenient and restrictive of traffic, because, in order to return the staff to A to allow a second train to go from A to B, there must be a return train ready to start from B to A, or the staff must wait at B until this is the case. On many lines the tide of traffic is one way in the morning and the other way in the evening, and speaking generally it is desirable to have the power at times of sending a succession of trains following one another in the same direction without waiting for return trains.

To get over this difficulty, the 'train-staff and ticket' system was devised. This system allows a station-master to give a ticket to an engine-driver instead of delivering to him the staff, provided that he exhibit the staff to the driver when he gives him the ticket. Thus any number of trains may follow one another, each with a ticket, and the last train may carry the staff to the other end of the district; and the same operation can be then carried out with the return trains from that end of the district. As a check on the station-master, the staff is sometimes so made that it alone will unlock a special box in which the tickets are kept. The safety of this system is not so great as that of the 'train staff' without tickets, as there is with the ticket system greater opportunity for laxity in carrying out the regulations on which it depends. It is, nevertheless, a very valuable way of providing for the difficult problem of working single lines with elasticity, and with a very near approach to safety.

Probably the best arrangement for a single line working is the train-staff and ticket system combined with the electric telegraph, which may be employed for the purpose of transmitting verbal messages (which, be it remembered, should always be written out), or for use under the ordinary block system, worked by speaking instruments. If the single line is worked wholly or partly by telegraph, recollect that every signal should be invariably repeated by the recipient of the signal, whether the signal be a verbal signal or one by the bell-code.

I will now endeavour shortly to describe some of the operations which are taken in hand for getting vehicles which have been run off the line—which are derailed, as the Americans say—back again on to the road. A train off the line is certainly a piteous object, even if the vehicles be standing upright on their wheels, but if, as

sometimes happens, they are on their sides, or turned upside down, it requires a cool head to set to work with judgment and yet with rapidity and vigour to clear the line.

If, as sometimes happens, the power of the locomotive cannot be brought to bear to get carriages back to the rails, everything must be done with screw-jacks or long levers. I need not refer to the modes of using long levers further than to caution you to be very careful in preparing a steady fulcrum, with an ample base, and in providing against the possibility of the lever slipping either on the fulcrum, or at its point of application. In almost all cases screw-jacks are much more handy than levers, but levers can almost always be procured where screw-jacks are perhaps not forthcoming.

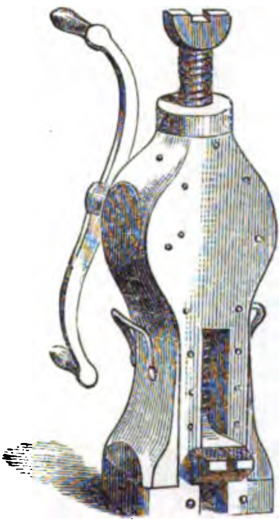


Fig. 167. Lifting jack.

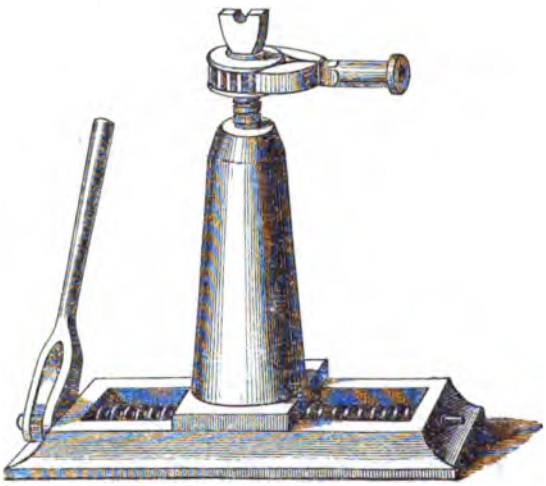


Fig. 168. Lifting and traversing jack.

A screw-jack is an apparatus for lifting great weights by manual labour, and is a most useful contrivance. An ordinary screw-jack for moderate lifts is shown in

fig. 167. There are much more powerful screw-jacks, but, of course, in all cases the speed will vary inversely with the weight lifted, the available manual power being supposed to be constant. An extremely useful addition is made to many screw-jacks in the traversing gear (fig. 168), by which, when a weight has been lifted, it can be moved sideways to the extent of the length of the base of the screw-jack, by turning the handle at the end of the traversing screw.

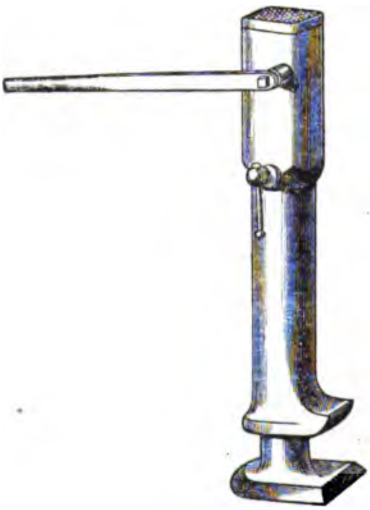


Fig. 169. Hydraulic lifting jack.

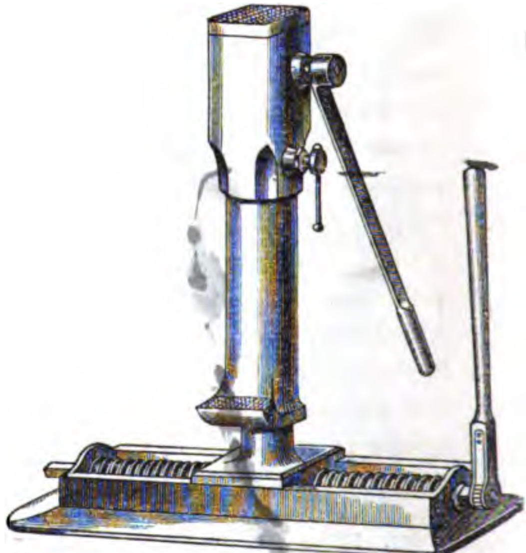


Fig. 170. Hydraulic lifting and traversing jack.

Besides ordinary screw-jacks there are small hydraulic presses mounted in a very portable form, and some are fitted with hand-traversing gear. These hydraulic presses, in figs. 169 and 170, are very useful for heavy lifts such as are sometimes necessary in raising a locomotive. On most English lines a couple of screw-jacks are carried on every locomotive, and in providing for working a temporary line this provision should not be lost sight of.

In dealing, then, with an upright derailed engine or carriage, we will assume that we have no locomotive power, but that we have four screw-jacks. We should require plenty of what is called packing—that is, pieces of timber of handy sizes and of rectangular section, such as portions of sleepers—to place beneath the carriage as the jacks lift it, to take its weight whenever it is necessary to shift the jack, and to provide against the risk of the screw-jack slipping, or of any accident happening to it. To get a derailed vehicle on to the line we have generally to lift its weight for at least 1 foot, and often much more. The top of the rail is usually 7 or 8 inches above the top of the sleeper, and the wheels have to be lifted about 1½ inches above the top of the rails in order to let the flanges of the wheels pass over the rail. Then, again, the wheels are probably imbedded some inches in the ballast; so that, under the most favourable circumstances, we shall, in the case of an empty carriage, have to lift 6 or 7 tons 1 foot high, which is an operation requiring a good deal of time, strength, and caution. In the case of a locomotive the weight is three or four times as much. It is, however, astonishing how quickly experienced people will see at once where to place the screw-jacks to the best advantage, where and when to put in or withdraw the packing. In all cases of dealing with derailed vehicles the springs should be rendered inoperative by blocks or wedges, as the play of the spring may give rise to some trouble in lifting or pulling the vehicle. I lately had occasion to lift the ends of two of the large engines, weighing about 42 tons, used on the Metropolitan District Railway, about 2 feet high, in order to use their weight suspended from a truss to test its strength. We raised and lowered the ends of those engines in each case eight times in less than 1½ hours with the help of two screw-

jacks to each engine, six men at each screw-jack, and about six more to each engine attending to the packings. In this case we had the advantage of experienced foremen, and we had everything prepared beforehand, so that all was done under circumstances which were very favourable, and very different to those which occur when an engine has run off the line, and has got all or any of its wheels altogether clear of the sleepers. In that case the first difficulty is to get a *point d'appui* for the screw-jacks to begin their work, and a safe bed on the ground for the packing to rest on.

In the case of carriages and waggons, it is usually only necessary to use long levers or screw-jacks for putting back on the rails those vehicles which are lying across the rails in a position in which a locomotive cannot approach or be coupled to them, or for turning a vehicle over so that it may be placed upright on its wheels. When an engine can be brought to bear on an upright derailed carriage, it is generally possible to get it on to the rails by pulling at it or pushing at it with the engine. In such cases a rough sort of road has to be prepared, along which the wheels can run till they are near enough and high enough to get on to the rails.

A very useful contrivance for this purpose is what is known as Stroudley's portable ramp, shown in fig. 171. The ramps are made of tough steel, and are attached to the rails near to the wheels of the derailed carriage, which is then pulled or pushed by the engine, so that the wheels run, travelling on their flanges, up the ramps till they run on to the rails at the top of the ramps. If the wheels are far laterally from the ramps, the vehicle must be towed sideways towards them, and this can easily be done if there be plenty of packing laid between and upon the sleepers.

When Stroudley's ramps are not forthcoming, the

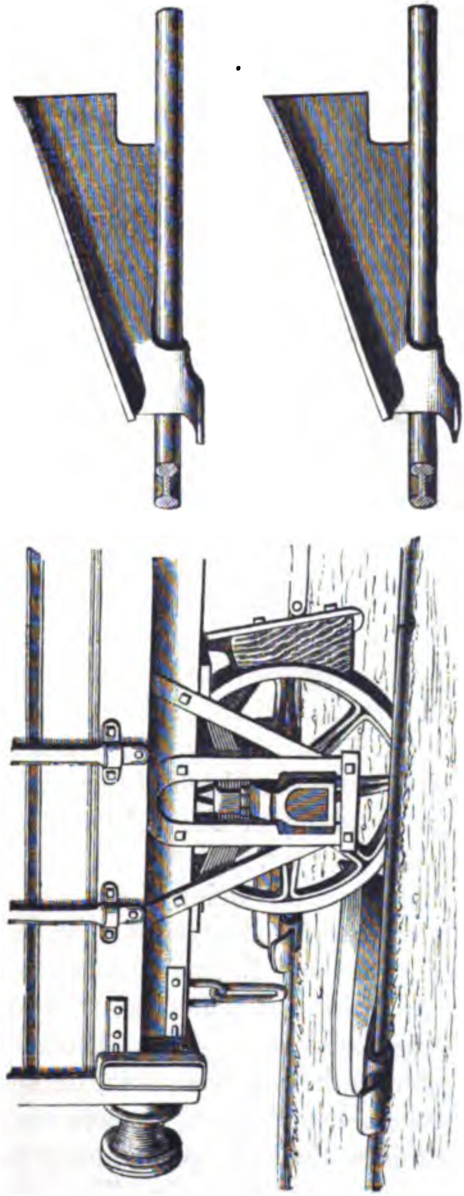


Fig. 171. Guide plates or ramps.

same function can be performed by timber packing so

arranged as to form inclined planes, up which the wheels can run on to the rails. Packings, when used for this purpose, are often inclined sideways, so as to cause the vehicle, when it is pulled by the engine, to travel in the direction required. It is to be remembered in all such cases that the packings will subside greatly when the weight of the vehicle comes on them, and good allowance must be made for this in arranging the packing. It is better to get the carriage too high than to fail of getting it on the rail for want of an inch or two in height.

Very often an ordinary crossing will act almost as well as a ramp as a guide for directing vehicles on to the rails, and if there be a crossing in the neighbourhood of a derailed vehicle it will often save a great deal of trouble. The vehicle will be pulled with the whole force of the engine till the wheels come to the crossing, and there it is obliged to jump up, and with the help of a little sideways pull will get on to the rails. A friend of mine got a very large engine on to the rails the other day in this manner. He had three engines on the rails to help, two pulling and one pushing the derailed engine to a crossing which directed the wheels of the derailed engine on to the line without any of the delays of screw-jacks and with very little packing.

A curious example of this action of a crossing occurred in the serious accident which happened some years ago at Wigan, on the London and North Western Railway. In that case a train divided at facing points, and the rear part ran off the line and was wrecked. The foremost part of the train continued its course for some distance at high speed, but the two last carriages of the foremost part had also run off the rails at the facing points, and yet continued attached to the fore part of the train. These two vehicles were drawn along at high speed for nearly half a mile,

with their wheels off the rails for the whole time, and bumping over sleepers and chairs till they reached a crossing, where they jumped on to the rails. When the fore part of the train stopped, the two hindmost carriages were found on the rails, and so far as their under carriages was concerned were almost uninjured.

From this you will appreciate what I said a short time ago about the amount of brutality which we may use towards both rolling stock or permanent way. When a stoppage takes place from a train having run off the road, the great thing generally is to get the line open, and one must not consider too much whether or not a little damage to the rolling stock or permanent way may be occasioned in so doing. Such damage is very readily repaired, and is seldom worthy of much consideration, compared with the importance of clearing the line.

Do not suppose, however, that because a vehicle looks all on one side, and appears ready to topple over, you can clear the line best by tumbling it over out of the way, unless you have considered how far you will have to lift one side of it. It may not be such an easy job as it looks, for in spite of its appearance the centre of gravity may be well within the base.

In all operations such as those I have briefly described, the value of consentaneous effort will be apparent. If there are four screw-jacks at work at lifting an engine or carriage, they must all be worked under the command of one man, and should very often be worked synchronously. In traversing, the greatest care is necessary to prevent any unequal stress or sideways nip on any point which would result in damage to the screw-jack, or some worse disaster. The screw-jack should be treated lovingly, and with none of the brutality on which we may venture with respect to the permanent way or rolling stock, for the value

of every screw-jack in a railway disaster is great, and it cannot generally be replaced or readily repaired.

All railway companies have what is termed a break-down train, which consists of one or two vans loaded with screw-jacks, packings, ramps, and other appliances for use in getting vehicles back to the rails. There is usually in such break-down trains a crane, mounted on a truck, and capable of lifting from 10 to 20 tons, which is often extremely useful in picking up vehicles which have been turned over, or for lifting one end of an engine. In the break-down train there ought to be also spare fish-plates, bolts, chairs, fang-bolts, spikes, and other small articles for use in repairing the permanent way, and it can do no harm to have some surgical stores as well.

It is, I think, so important that an engineer likely to have charge of a military railway should have some practical appreciation of how derailed vehicles can be dealt with, that I venture to suggest that if ever you meet with an engine or even a carriage off the rails, you should, even at some sacrifice of time, wait and see the way in which the foremen and workmen accustomed to such work proceed to get it on the line. One such example would be ten times as useful as any remarks I can make here.

In conclusion I must thank you for the attention with which you have listened to this course of lectures, including as it has done a mass of details which, I fear, must have been at times anything but interesting, and I must apologise for my shortcomings in the art, for it is an art, of lecturing. I trust at any rate you will believe that it has been a sincere pleasure to me to come amongst you, and that I have endeavoured, to the best of my ability, to bring before you some of the matters of which experience has shown me the utility in railway making and railway working.

THREE LECTURES

ON

LOCOMOTIVES

DELIVERED AT

THE SCHOOL OF MILITARY ENGINEERING, CHATHAM

December 3rd, 10th, and 17th, 1877

BY

F. J. BRAMWELL, F.R.S., M. INST. C.E.

RAILWAYS AND LOCOMOTIVES.

LECTURE I.

EARLY LOCOMOTIVES—MODERN LOCOMOTIVES—PRINCIPLES OF DESIGN—HORSE-POWER—TRACTION—WEIGHT ON WHEELS—USE OF STEAM—TYPES OF MODERN LOCOMOTIVES—CONSUMPTION OF FUEL—BOILER—SAFETY VALVE—INJECTOR.

I DESIRE to say at the outset that under the title 'Locomotive' I intend to include (if I have the opportunity) not only the Railway Engine, but also some, at least, of the various forms of engines which from time to time have run on ordinary roads; and I further wish to state that, looking at the fact, that even a comparatively superficial knowledge of the engines which are now doing the work of our railways is of much more practical utility than the most intimate acquaintance with the mere history of the locomotive, I propose to devote but a very small portion of the limited time at our disposal to the historical branch of our subject.

Indeed I will, with your permission, dismiss the historical portion with the following few and brief references.

Setting aside sailing chariots, the first locomotive, so far as I am aware, was one to be used on common roads, and was that of Cugnot, actually put to work in the streets of Paris, in the year 1769. A second engine, made in 1771, still exists in the Conservatoire des Arts

et Métiers at Paris; and a model of it was in the last year's Loan Exhibition of Scientific Apparatus.

These engines were three-wheeled: the single wheel was in front and was the driving wheel. This wheel

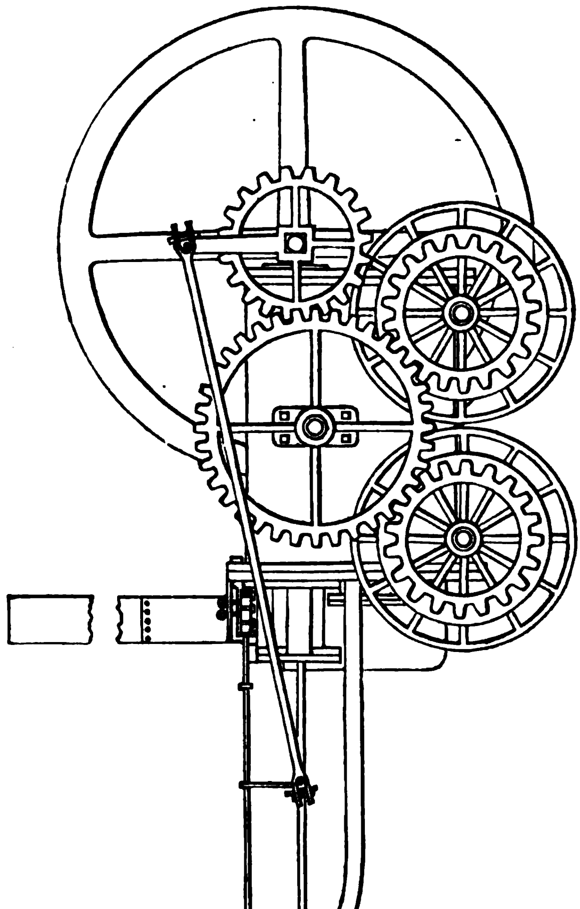


FIG. 1. Trevithick's locomotive, 1804.

was caused to revolve not by the aid of cranks, but by the alternate action through racks and pinions of the pistons of a pair of single-acting vertical engines. The boiler

and engines were on the fore carriage, and thus when the locomotive was steered, the boiler, and all the machinery, were moved round by the steering handle: a construction which within the last few years has been repeated by Mr. Perkins.

It is stated that Cugnot's engine attained a speed of about two and a quarter miles per hour, but that it had to make repeated stoppages to give time for the steam to accumulate in the boiler. It was an imperfect machine, no doubt; nevertheless it possesses great interest as a bold experiment.

Merely mentioning the name of Trevithick, who in 1804 made a locomotive (fig. 1) which drew a load along a plain-surfaced cast-iron tramway, and had the exhaust steam from its cylinders directed into the chimney, I will pass on to Murray's engine, which in 1812 was running on rails, and drawing loads after it; the requisite traction being obtained by means of teeth on a side flange of the bearing wheels engaging in projections on the side of the rail—the 'Blenkinsop rail.' A length of such a rail, one which was in actual use for many years, is now before you.

Quite recently the same principle has been revived, in the case of the Righi Railway; modified, however, in construction by the placing of the teeth between two parallel bars, thus forming a ladder-like rail, which is used in the centre for traction only, while two plain outer rails bear the weight of the engine; as shown in fig. 2. With this construction, inclines as steep as one in four are surmounted.

In the year 1813 the celebrated 'Puffing Billy' (fig. 3) was put to work. This was an engine that ran as Trevithick's had done on plain surfaces (but the surfaces were those of rails and not of trams) and that derived its

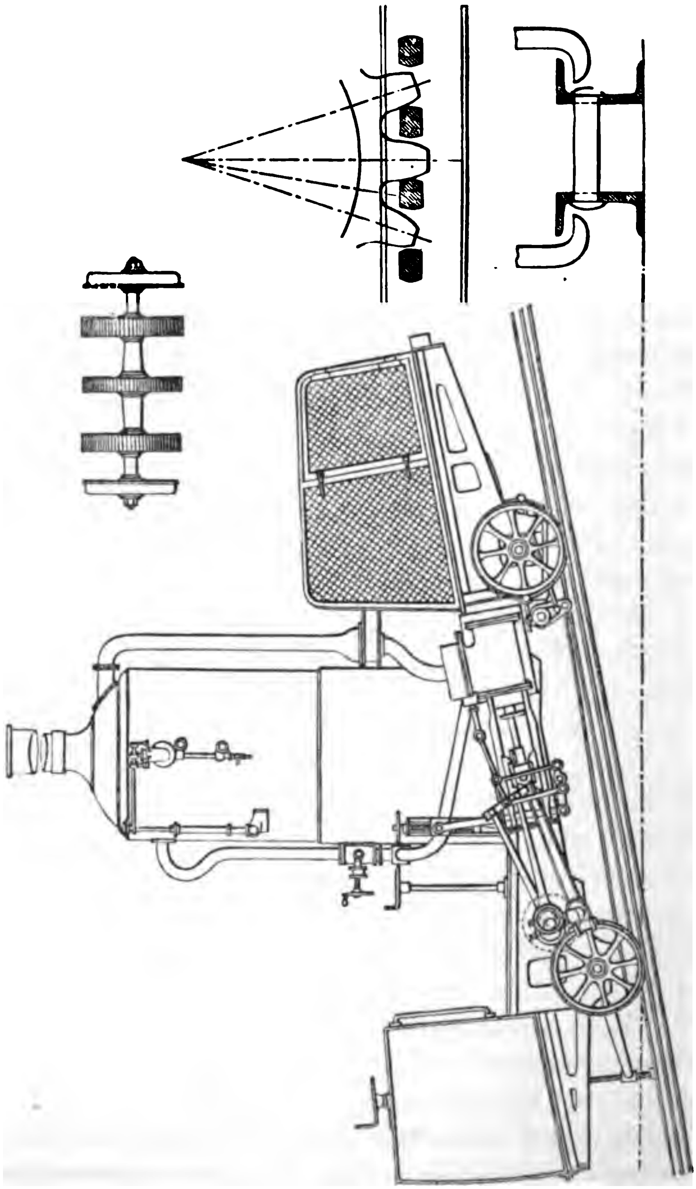


FIG. 2. Locomotive for Righ Railway.

tractive power from the mere frictional contact between the wheels and the rails. Puffing Billy continued at work until the year 1862, and made an honourable appearance at the Scientific Loan Collection of 1876.

There are some very interesting incidental remarks on locomotives, contained in a 'Blue Book' of the year 1817 on the subject of Boiler Explosions, proving that at

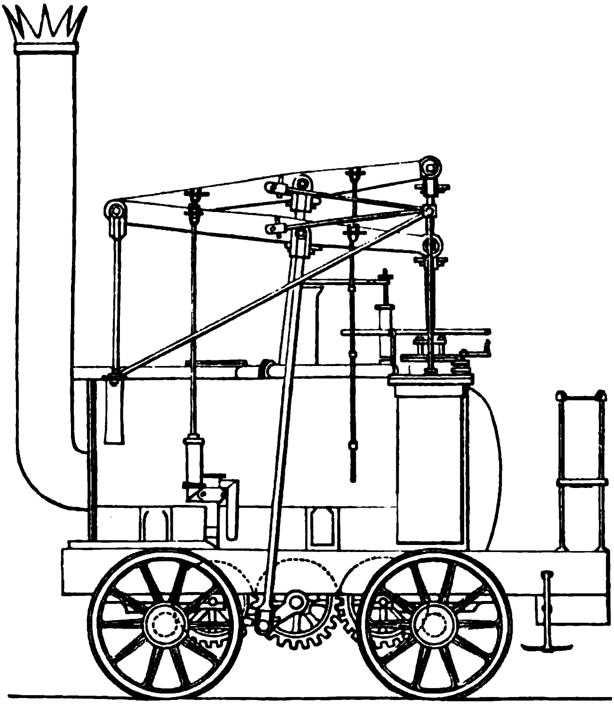


FIG. 3. 'Puffing Billy,' 1813.

that date the existence of locomotives was not generally known; for instance, Mr. Chapman stated to the committee 'there are a description of engines in use in the counties of Durham, Northumberland, Cumberland, and York, that are termed Loco-motive engines.' This same gentleman also said 'that a boiler may last twelve months, safely,

provided its bottom be made of charcoal iron, beat, not rolled.'

I will omit any extended reference to the opening of the Stockton and Darlington Railway in 1825, and will pass on to that of the Manchester and Liverpool Railway in 1830, with Stephenson's 'Rocket,' having inclined

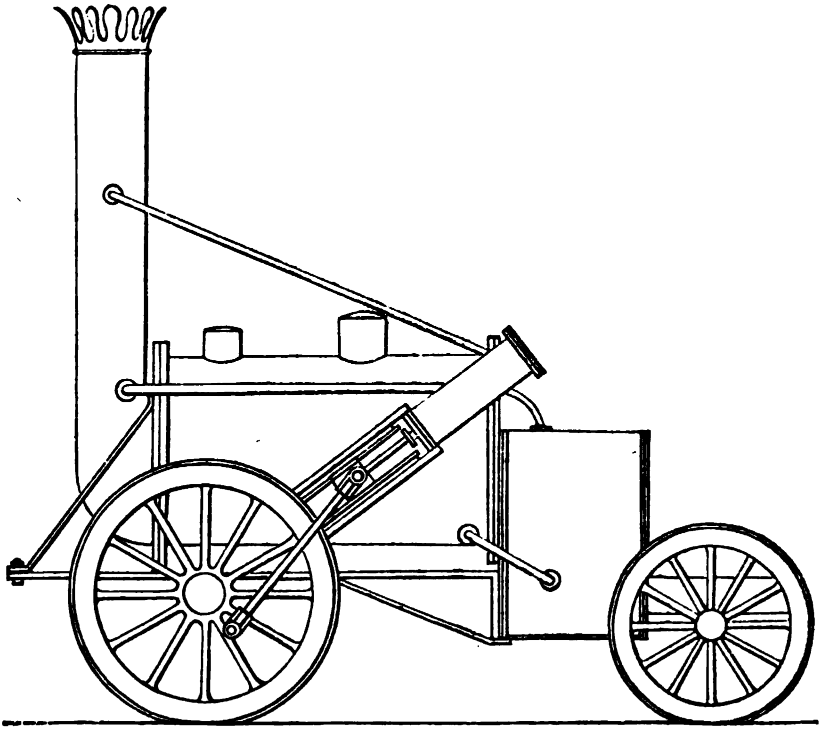


FIG. 4. 'Rocket,' 1829.

cylinders and a multitubular boiler. This engine was also shown at the Loan Exhibition, but in a somewhat altered condition; by the kindness of Mr. George Robert Stephenson, however, I am enabled to place before you an accurate model of the engine as first constructed. The model

was made by a man who drove the engine. Fig. 4 shows a side elevation of the model.

Having said this much, or rather this little, I will pass away from history and will go to the real subject of these lectures, the railroad locomotive of the present day.

First, let us inquire what are the ends to be attained by a locomotive; then, let us consider how an intelligent engineer would set himself to devise a machine which would fulfil those ends; and then, let us further consider how far those ends are actually fulfilled in practice.

The ends sought are: the ability to draw very considerable loads, even in the case of passenger trains, and much heavier loads in the case of goods and mineral trains, and the obtaining of high speed, even for the heaviest goods and mineral trains—high when compared with any horse traction, and excessively high speed in the case of passenger trains. We must remember, that the locomotive which has to fulfil these ends, although, as a rule, it has to do so upon a line which is made as level and as straight as possible, may have to fulfil them upon a line which is not level, and upon one which has very considerable curves. And lastly, it is necessary that these ends should be attained, not only under the conditions mentioned, but also under the further conditions of safety and of economy.

The ends being stated, let us now consider how an intelligent engineer would set about designing a machine to fulfil them.

He would say, I must be able to develop a sufficient power, I must be able to utilise this power as traction, I must have a steam generator which shall be safe, a steam engine under thorough control, and an en-

gine that will work with economy; and I must have the whole upon a carriage which will not be liable to leave the rails, which will accommodate itself to the curves of the line, and which will travel over a rough road without, by its joltings, damaging itself, or damaging that on which it runs.

As regards the power:—to overcome the wheel friction and the axle friction, and to overcome the resistance of the air, there is required a very considerable traction per ton of weight moved. Taking the resistance per ton of weight of train, for any particular speed, and multiplying that into the number of tons and into the speed of the train in feet per minute, and dividing by 33,000, there is obtained the horse-power which must be exerted by the locomotive to move itself and the load behind it at the speed under consideration. On making the calculation, we shall find the resulting horse-power very large. When I say very large, I do not mean large as compared with the horse-power of some marine engines, but I mean as compared with the ordinary run of fixed engines for manufacturing purposes, and it must be borne in mind that this power has to be developed in a machine which commonly is supported upon rails of 4 ft. 8½ in. gauge, which must not be too long to be manageable round curves, and must not be so high as to be topheavy.

The first thing, therefore, that the designer of an engine has to consider is, what power must it be capable of developing?

Experiments have been made to determine the resistance to traction on a level straight road per ton of load at varying speeds. Let us apply the information thus obtained to a passenger train.

A fair weight for a loaded passenger train drawn by one engine may at the present day be taken at, say, 95

tons, and the weight of the engine and tender in working order to draw it may be estimated at 55 tons: equal to a total of 150 tons. Assuming 50 miles an hour as the speed of the train, irrespective of stoppages, and $22\frac{1}{2}$ pounds per ton as the resistance to traction at that speed, we find that the horse-power necessary for the traction of the train, including the engine and tender, will be:—

Weight in tons		Speed in feet per minute		Lbs. traction per ton at 50 miles per hour		H.P.

$$\frac{150 \times 4400 \times 22\frac{1}{2}}{33000} = 450$$

Take next the case of a coal train:—A fair weight for a loaded coal train to be drawn by one engine may be taken, including the engine and tender, at 500 tons, and a fair speed, irrespective of stoppages, for such a train at 25 miles an hour; under these circumstances, and with a resistance to traction of 16 lbs. per ton, the horse-power will be:—

Weight in tons		Speed in feet per minute		Lbs. traction per ton at 25 miles per hour		H.P.

$$\frac{500 \times 2200 \times 16}{33000} = 533$$

To the horse-powers above shown, which are the effective powers delivered off the rims of the wheels of the engines, must be added about one-fifth for the losses in the engines themselves. This proportion has been ascertained by very careful experiment with engines of a construction similar to that of the locomotive. These experiments showed that on an average one-sixth was the deduction which must be made from the gross horse-power developed upon the pistons, before counting upon the net horse-power delivered by the engines. This correction of one-sixth off the gross, or one-fifth on to the nett, will bring

up the gross horse-power of the passenger engine to 540, and the gross horse-power of the goods engine to 640.

Setting aside, for the moment, the question of how these horse-powers are to be obtained, the next point the engineer should consider is the means of ensuring the requisite adhesion to utilise these powers as traction.

It has already been stated, that in the assumed case of the passenger train of 150 tons travelling 50 miles an hour, the traction required amounts to 22½ lbs. per ton, or a total of 1·506 tons, and in the case of the goods train travelling at 25 miles per hour, it would amount to a total of 3·57 tons.

The Blenkinsop rail being discarded and the Righi rail, to which I have alluded, and the Fell system, which I propose hereafter to briefly mention, not being used, the engineer is confined, as his *point d'appui* for the traction, to the friction between the tyres of the wheels, and the surfaces of the rails; and experience has shown that the resistance to slipping, *i.e.* the power of drawing a load, cannot be taken at more than one-sixth of the insistent weight on the driving wheels, unless sand be used. It follows, therefore, that in the case of the passenger locomotive under consideration there must be on the wheels which propel an insistent weight of at least 9 tons, and in the case of the goods engine under consideration of at least 21½ tons. These, however, are the requirements when on a level line, and when, therefore, the opposition of gravity has not to be taken into account; but when inclines of one in one hundred are dealt with—and such inclines are by no means uncommon, even for long distances—then it is clear, that from the passenger engine drawing a train of a gross weight of 150 tons there will be demanded a traction of 1½ tons in addition to the 1·506 tons required on a level, making a total of 3·006

tons; and, in the case of the goods engine, an extra traction of 5 tons, making a total of 8·5 tons.

To give this power of traction, the insistent weight, therefore, on the wheels which propel, in the case of the passenger engine should be as much as 18 tons, and in the case of the goods engine as much as 51 tons. This latter weight is in excess by some 10 tons of the weight of heavy goods engines, but the ability of the lighter engine to draw the load up such an incline arises from the fact that the speed is there materially reduced, and as the resistance to traction falls with the speed (although not in the same ratio), the 8·5 tons traction which must have been exerted to mount the incline at full speed may readily be reduced to some 7 tons at the diminished pace.

Now the weights in the locomotive must be so distributed as to be bearable by the axles of the engine itself, by the tyres of the wheels, and also by the rails upon which the engine runs.

Even with steel tyres and steel rails, practice has not hitherto gone beyond 8 tons upon each point of support, or 16 tons upon each pair of wheels; and both the Locomotive Engineer and the Engineer of the Permanent Way would be glad to reduce these weights to 7 or even to 6 tons per point of support; that is, to 14 or even to 12 tons per pair of wheels.

In the case of the high speed and the comparatively light load of a passenger engine, the old construction shown on the sketch diagram fig. 5, that of a central pair of driving wheels, a pair of leading, and a pair of trailing wheels will suffice to give sufficient adhesion, but only by the reduction in speed up the supposed incline, causing a diminution in the traction; as the 3 tons stated would demand 18 tons weight on the driving wheels,

whereas the maximum load on an axle does not, as has already been mentioned, exceed 16 tons, equal to an adhesion of only 2⅔ tons in lieu of the 3 tons required.

For a goods engine, however, it is necessary, in order to obtain sufficient adhesion, that the whole weight of the machine should be borne by wheels which drive; if this be done, then, taking such an engine in its working order to weigh 42 tons, there is obtained the ability of exerting the traction of 7 tons already mentioned.

Of late years passenger engines for ordinary work have been made with two pairs of wheels coupled to

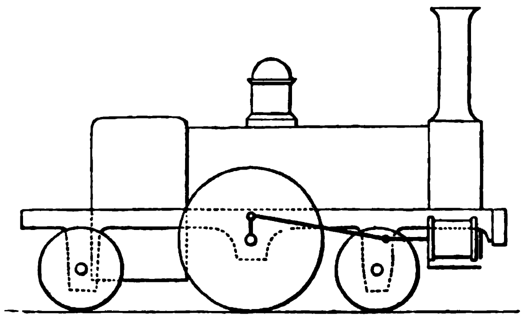


FIG. 5. Passenger locomotive, 1831.

drive; on which two pairs of wheels there are probably as much as from 24 to 30 tons of weight, permitting of from 4 to 5 tons of traction.

The next point the engineer has to consider is, how to produce, within the limited space at his command, the requisite horse-power, and to do so with safety and with economy in working.

The horse-power developed will depend, it need hardly be said, upon the velocity of the pistons multiplied into their area, multiplied into the mean effective pressure upon the pistons.

The first question that arises in this calculation is,

'What is to be the velocity of the piston?' The length of stroke is necessarily limited; about 2 feet or 2 feet 2 inches is probably the longest stroke generally used in practice, the maximum stroke known to me is 2 feet 4 inches. As the length of stroke cannot, because of practical objections, be increased at will, the speed of the pistons must depend upon the number of reciprocations; and as in all ordinary railway locomotives, gearing is abandoned and the engines are connected directly to the crank pins of the driving axles or to crank pins on the wheels, the number of reciprocations is governed by the speed at which these wheels revolve. This being so, it is readily seen why, in order to obtain an approach to uniformity in the velocity of the pistons in different classes of locomotives, it is desirable that a high-speed engine should be made with large wheels, and a low-speed engine should be made with small wheels.

For example, take a passenger engine to run at 50 miles an hour, and with a 7-feet 6-inch wheel. Such a wheel would make 186 revolutions per minute. Take on the other hand a goods engine, with 5-feet wheels running at 25 miles an hour, such a wheel would make 140 revolutions per minute. I may perhaps be pardoned for reminding you, at this point in my lecture, of a convenient rule for mental calculation, and that is, that a wheel one foot diameter, making 28 revolutions per minute, travels at a speed of a mile an hour. These figures are easily remembered, because the diameter of the wheel and the speed are each unity, while the 28 is the number of pounds in a quarter of a hundredweight. With the passenger engine wheel, running at 186 revolutions per minute, and with engines having a stroke of 21 inches, the piston velocity would be 651 feet per minute; while with the goods engine wheel, making

140 revolutions per minute, and with engines having a stroke of 26 inches, the piston velocity would be 606 feet per minute.

Next, as to the load on the piston.—Applying these speeds to the horse-powers we have previously ascertained, we find that in the case of the passenger locomotive:

$$\frac{\overset{\text{H. P.}}{540} \times 33{,}000}{651} = \overset{\text{Mean load on the pistons}}{27{,}370 \text{ lbs.}}$$

Such an engine would probably have two 16-inch cylinders, the combined area of their pistons would be about 400 square inches, and dividing the mean pressure of 27,370 lbs. by 400, there is obtained 68 lbs., as the mean pressure per square inch on the piston.

Similarly, dividing the 640 horse-power of the goods engine by the piston speed of 606 feet, there is obtained a mean load of 34,851 lbs. on the pistons:

$$\frac{\overset{\text{H. P.}}{640} \times 33{,}000}{606} = \overset{\text{Mean load on the pistons}}{34{,}851 \text{ lbs.}}$$

And 34,851 lbs. being divided by 510, the area of the two cylinders (in this case assumed as 18 inches diameter), gives also a mean pressure per square inch on the piston of 68 lbs.

I have pursued the calculation of the tractive force by the old roundabout method, but it may be as well to state in passing that the simple rule for ascertaining it, is to square the diameter of one piston, to multiply the square by the stroke in inches, and to divide by the diameter of the wheel in inches: the result will be (neglecting in all cases the slight deduction to be made for the area of the piston rod, viz. about $\frac{1}{72}$) the gross

traction for each pound of mean effective pressure on the pistons, from which apparent power of traction however must be deducted one-sixth for the internal resistance of the engine itself.

To obtain the 68 lbs. mean pressure we have arrived at, it obviously would suffice, if there were maintained in the cylinder, throughout the whole stroke a supply of steam at a uniform pressure so much in excess of the 68 lbs. mean effective pressure required, as would be equivalent to that pressure, plus the back pressure of the exhaust steam, which we will assume to be equal to 5 lbs., in other words a uniform pressure of 73 lbs. above atmosphere, or 88 lbs. above zero, would produce the 68 lbs. mean effective pressure.

But such a mode of using the steam would not only be wanting in economy, but would be wanting in certain advantages of detail, very essential to the smooth working of engines reciprocating a great number of times in a minute.

I presume I am addressing gentlemen thoroughly acquainted with the theory of steam, and of its expansive action, and with the advantages arising therefrom; but in order to avoid the risk of leaving a serious gap in this lecture, I think it well, even should I be telling you that which you already know, to call attention to the question of the economic use of steam.

Let me here say that, throughout the following illustrations of the economic use of steam, I intend, as they are only illustrations, to commit certain inaccuracies for the sake of simplicity, that is to say, I intend to take 15 lbs. as the pressure of the atmosphere, and to assume that the density of the steam varies directly with its pressure, and inversely as its volume. I am aware these assumptions are inaccurate, and at certain pressures very inaccurate, but they will suffice for illustrative

purposes. I have hung upon the wall diagrams and tables of the correct relations of weight, volume, and temperature at varying pressures, to which I shall refer if need be. (See figs. 6 and 7.)

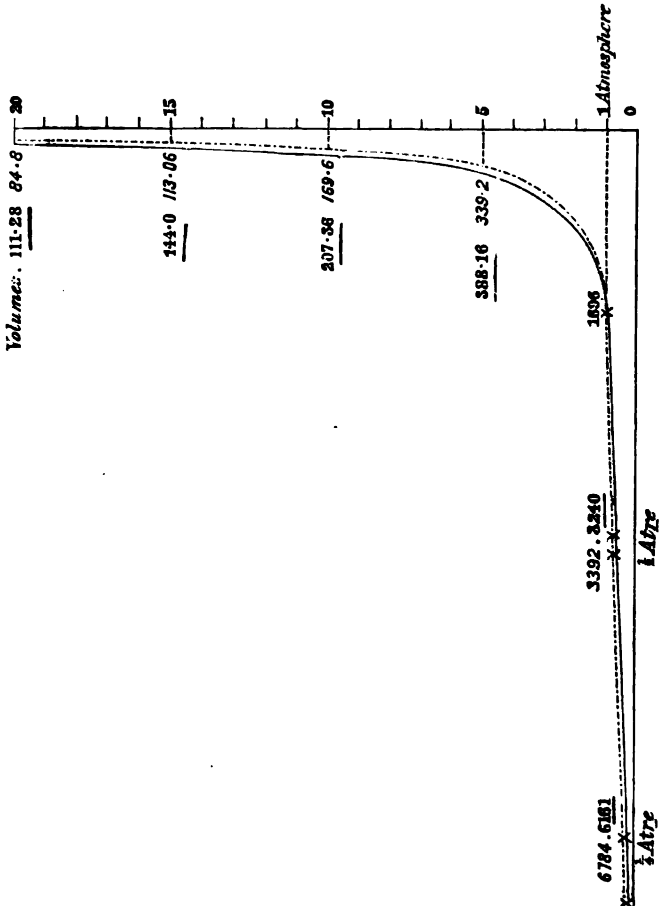


FIG. 6. Diagram showing by the dark (underlined) figures and full lines the actual volumes of steam (water being unity), and by the light figures and dotted lines the volumes calculated on the assumption that the density is inversely as the pressure.

Leaving expansion on one side for the present, let us consider the economy (in non-condensing engines) of using high-pressure steam. Take the case of a given weight of water, say 1 lb., being converted into 1 lb. of

steam per minute, but at a pressure no greater than that of the atmosphere. It is obvious that that steam, in a non-condensing engine, could do no work, inasmuch as its pressure would be only just sufficient to balance that of the atmosphere, and that therefore the whole of the fuel consumed in boiling off the water would be wasted.

Take, as a second case, the same weight of water converted into steam, but at a pressure of two atmospheres

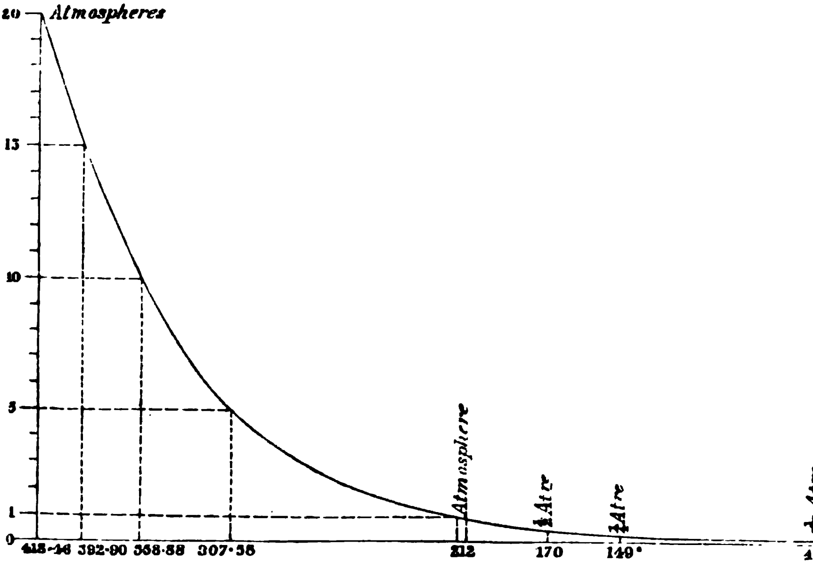


FIG. 7. Diagram showing temperatures of steam at varying pressures.

above zero; then the effective pressure will be one atmosphere, and half only of the fuel will be wasted. Without going through the successive stages, let us next consider what would happen if the steam were generated at a pressure of, say, 11 atmospheres above zero: then ten of these 11 would be effective, and one, only, would be thrown away, or $\frac{1}{11}$th, instead of the $\frac{1}{2}$ of the fuel which would be wasted, when working a non-condensing engine with steam at only two absolute atmospheres of pressure.

Within reasonable limits, there is therefore manifestly, irrespective of expansion, an economy in working a non-condensing engine with high-pressure steam.

Let us now consider the value of expansion.

First, we will assume the case suggested of working without any expansion at all, and of attaining the required 68 lbs. of effective pressure above atmosphere by the employment throughout the whole stroke of steam at 88 lbs. above zero. The 88 lbs. are arrived at, as I have already shown, by adding the assumed 5 lbs. back pressure in the cylinders, and the 15 lbs. pressure of the atmosphere, to the 68 lbs. effective required. The weight of steam used under these circumstances would be the cubic contents of the cylinders multiplied by the density of 88 lbs. steam, which I will call $5\frac{13}{15}$ atmospheres$=5{\cdot}86'$, or, treating the cubic contents of the cylinders in a given time as unity, the weight of steam used would be $5\frac{13}{15}$.

Next let the steam be used expansively, that is to say, let us introduce steam of a pressure considerably in excess of the mean pressure required, but introduce it for a portion only of the stroke, instead of for the whole of the stroke, and allow it to carry on its work in the cylinder by expansion; we shall then find that if, for example, we take the boiler pressure to be that usual in first-class locomotives of the present day, *i.e.* 140 lbs. above atmosphere, or 155 (as we call it), above zero, and if, after allowing for reduction of pressure in passing through the pipes and passages, we assume it to be introduced into the cylinder at 147 lbs. above zero, and that the admission be continued for only one-fourth of the stroke and the steam be suffered to expand down to $36\frac{3}{4}$ lbs. above zero before it escapes into the atmosphere, it will give a mean pressure of 88 lbs. above zero. If the atmosphere pressure and the back pressure above atmosphere, taken

together, as before, at 20 lbs. be deducted, there will remain the mean effective pressure of 68 lbs. required. But the weight of steam now used will be only one-fourth of the cubic contents, multiplied however by the heavier density of $9\frac{4}{5}$ atmospheres, or a weight of 2·45, as compared with the weight of 5·86′, which must have been consumed, had steam of only 88 lbs. ($=5\frac{13}{15}$ atmospheres) above zero been used throughout the whole of the stroke.

With such pressures and expansions as these, it is possible to obtain a gross indicated horse-power (that is to say, the horse-power shown by the indicator as being exerted by the piston) for as little as $\frac{1}{2}$ cubic foot, or $31\frac{1}{4}$ lbs., of water, per horse-power per hour. To evaporate a cubic foot of water in a locomotive boiler by coal (the common fuel of the present day) demands from $6\frac{1}{2}$ to $8\frac{1}{2}$ lbs., according to the quality of the fuel. Take $7\frac{1}{2}$ as a fair mean, and there is obtained a consumption of $3\frac{3}{4}$ lbs. of coal per hour for each gross indicated horse-power, a consumption comparing very favourably indeed with that of the average non-condensing engines used for manufacturing purposes.

Even with this low consumption of $3\frac{3}{4}$ lbs. per horse-power per hour, you will find, if you take the pains to multiply together the horse-power and the consumption and to divide by the speed per hour, there results an expenditure of fuel per mile largely in excess of that shown by the published returns of the Railway Companies. The explanation of the discrepancy is to be found in the fact that the returns given by the Railway Companies are the averages, and include light loads, empty trains, and low speeds, whereas I have been laying before you the maximum duties which engines such as we have considered may be called upon to perform; for which duties, therefore, the designer of the engines must make provision.

I believe I have now prepared the way sufficiently to

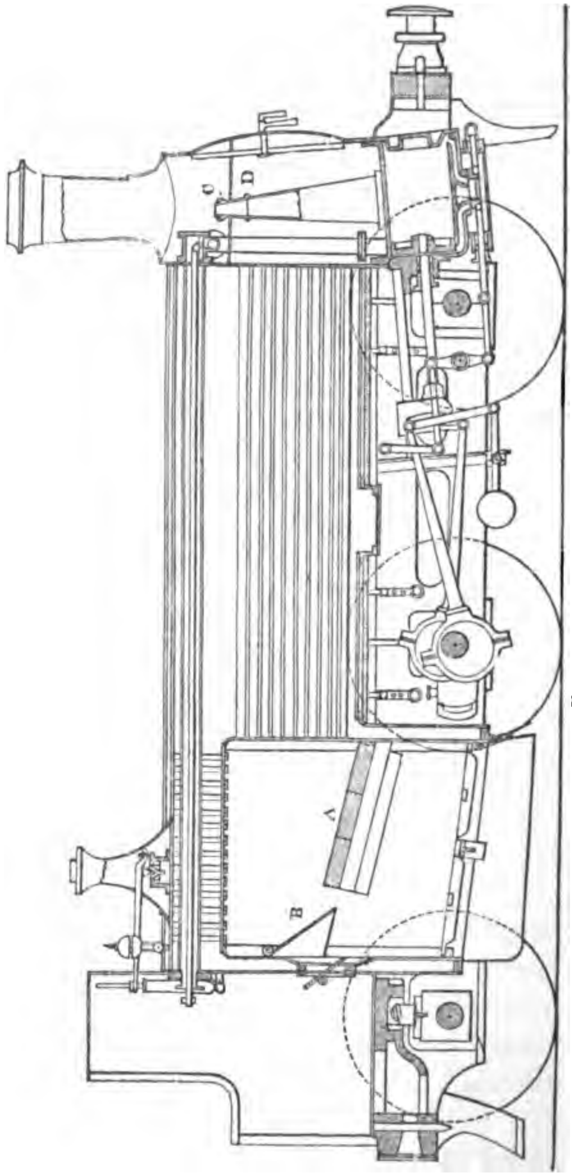


FIG. 8. Section of goods locomotive.

enable us to look into, and to advantageously consider, the

construction of the actual locomotive now in use, and to

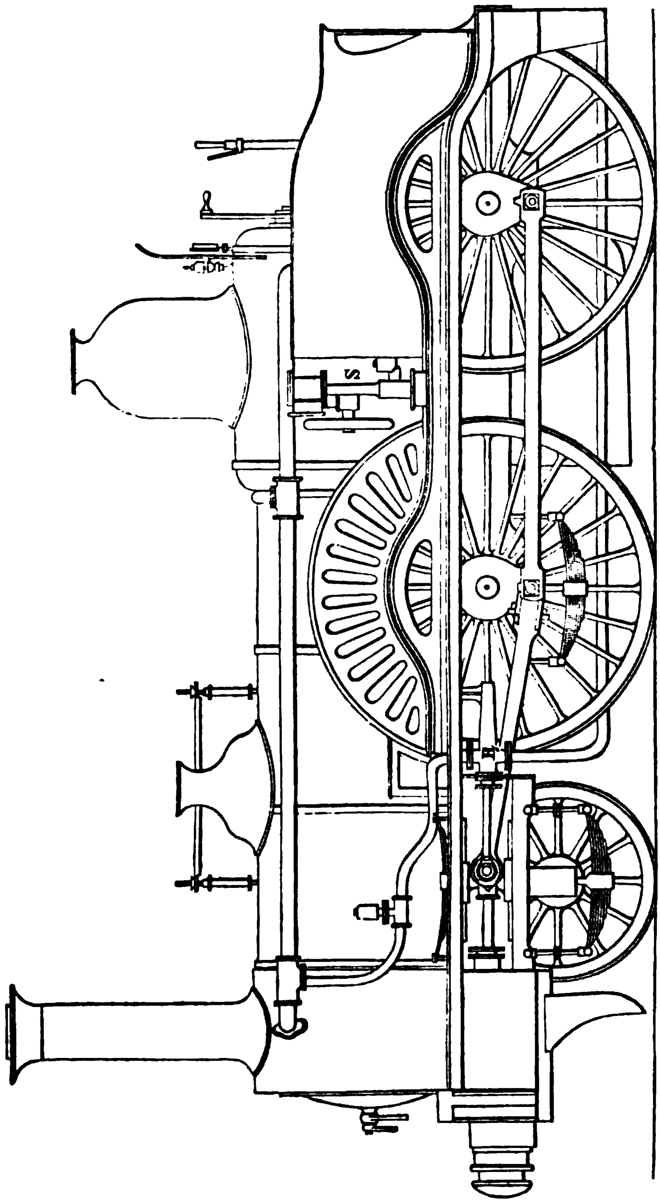


Fig. 9. Passenger engine.

see how far it fulfils the various ends, and the conditions

indispensable in obtaining those ends which we have found it should fulfil.

Having regard to our limited time, I will bring before you only three complete diagrams of locomotives, and I will select for these the three most ordinary types of engines in use at the present day, leaving for separate diagrams such deviations from these types as I may be able to bring under your notice.

The first of these diagrams (fig. 8) shows a longitudinal section of a goods engine with all its six wheels coupled and acting as driving wheels, and with inside cylinders. The second diagram (fig. 9) shows an outside view of a passenger engine, having a pair of leading wheels, and having the four hinder wheels coupled to drive; the cylinders being outside.

Both these engines are intended to be used with tenders.

The third diagram (fig. 10) shows a longitudinal section of a tank engine, *i.e.* an engine carrying its own water and fuel.

In each case we will commence our consideration with that soul of every steam-engine—the boiler. It will suffice to employ the same description for all three boilers. The problem, it will be remembered, is to boil off when working at the very maximum some 1,600 to 2,000 gallons of water per hour, or from 26 to 33 gallons per minute. To do this it is necessary, as indeed hardly need be said, first to ensure the combustion of an adequate amount of fuel, and then to provide a sufficient surface 'licked,' as the French say, by the flame on the one side and wetted on the other, to carry off from the products of combustion the heat evolved, and to transmit it to the water. To consume the weight of fuel I have mentioned, there would be provided in an ordinary land engine, or even in a

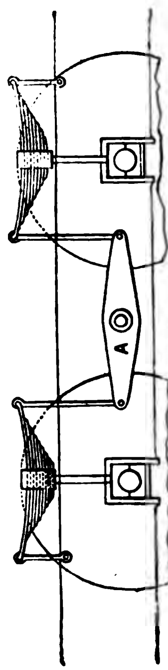


FIG. 10A. Balance Beam.

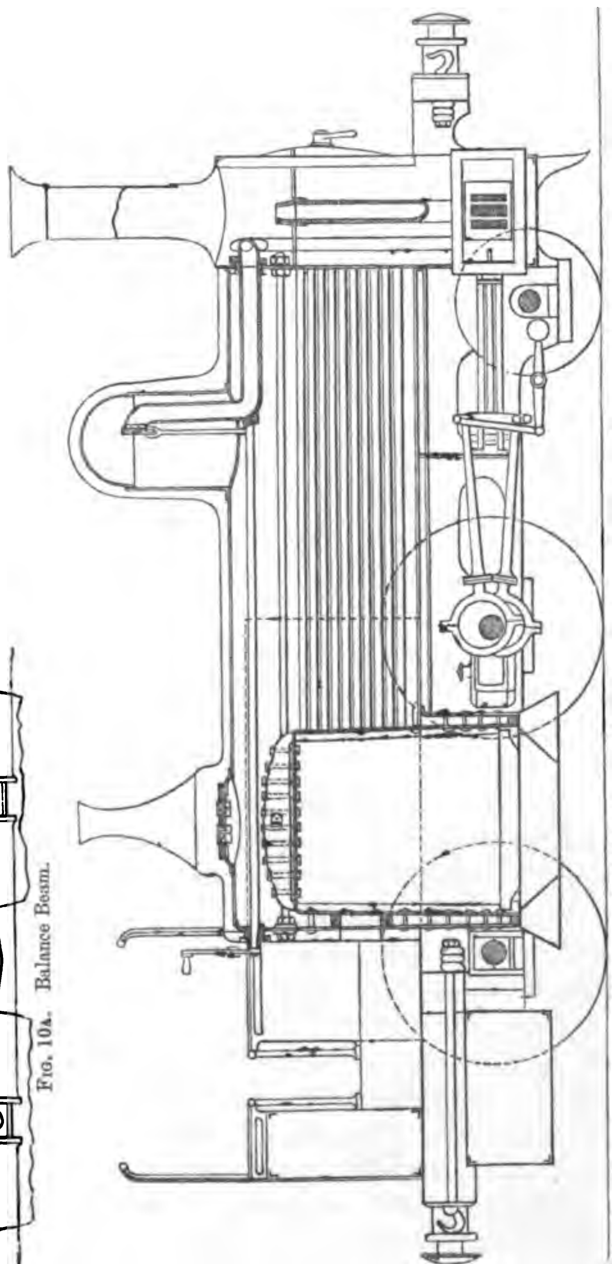


FIG. 10. Section of 'Tank' locomotive.

marine engine, a grate area of about 100 feet. To obtain such an area with the width possible in the fire-box of a 4′ 8½″ gauge engine (that is, possible, after making the requisite reductions for water spaces, metal, and clearance), a length of grate bar of 27 feet would be required.

Obviously, it would be impossible to satisfy such a requirement, and therefore for the combustion of the necessary weights of fuel reliance must be placed, not upon the mere area of the grate, but upon the mass of fuel contained in the fire-box. But the massing of fuel renders perfect combustion a still more difficult operation than it is under ordinary circumstances; and ordinarily it is difficult enough, as, even with a large grate area and with the fuel comparatively regularly spread, the ensuring a uniform and adequate supply of air to the fire is no easy matter, even with the use of lofty chimneys.

In the case of the locomotive, however, where, as we have said, there cannot be a proper grate area, and the fuel must be massed, the engineer is at special disadvantage, because, so far from having a loftier chimney than that which can be obtained, for a stationary engine, or for a marine engine, he is compelled to restrict himself to a funnel the very top of which must not exceed, say, 13 feet above the level of the rails. Under these circumstances he is driven to have some kind of forced draught. That draught might have been obtained, and, as we know, attempts were made to obtain it, by means of a blowing fan, but all such attempts have for some time, at all events, been relinquished, and the requisite power of draught is now universally got by means of the waste steam blast.

On looking at the section of the smoke-box, it will be seen that the orifice of the blast-pipe (the pipe which delivers

the exhaust steam from the two cylinders) is at a slight distance above the topmost row of tubes. The waste steam issuing from this orifice with the speed due to its pressure induces a current in the surrounding air, and carrying that air with itself up the funnel at a high velocity, there is necessarily obtained a partially vacuous condition in the smoke-box.

William Nicholson in 1799 translated Venturi's work upon the lateral communication of motion, in fluids. In this work, induced currents are mentioned as being used for the draining of marshes, while the application of the lateral or induced current in water for the purposes of moving larger bodies of water was referred to in Mr. Unwin's Lectures, delivered here in 1869.

In 1806 Nicholson patented the exciting the draught of a fire by means of an induced current caused by a jet of steam. I have here a rough model, made out of an ordinary blowing fan, to exhibit the production of an induced current.

To revert to the blast in the locomotive, it is by means of this, involving no machinery or moving parts of any kind, that the requisite power is obtained for forcing the air through the fire; but it is not found desirable—especially with coal—to introduce the whole of the air to the fuel from below; as if this were done, two objections would arise, one, that the air in its passage through the fuel, after having produced carbonic acid by perfect combustion in the lower part, might in the upper part take up a second portion of carbon and become converted into carbonic oxide, and then pass away with the carbon contained in it unconsumed; the other, that in burning coal, when the coal is freshly introduced, the hydro-carbons distilled off might also pass away without being consumed, causing an offensive smoke and some loss

of fuel. It is therefore in practice found to be desirable to admit a very considerable portion of air above the fuel. The regulation of these two inlets of air is made, for the one, by means of dampers applied to the ash-pan, and for the other, by means of slides or other analogous contrivances applied to the fire-door opening.

While on this subject, it may be well to allude to the smoke difficulty. Unhappily for the comfort of railway travellers, it was discovered some twenty years ago, that engines could be worked as effectually and in most districts more cheaply, by substituting raw coal for the coke previously employed, and, except under certain special circumstances or in particular districts, raw coal is the locomotive fuel of the present day. Efforts are made to burn the smoke, and when the firing is carefully done and the engine is not too much over-taxed, these efforts may meet with a very considerable share of success in obtaining the desired end even with a bituminous coal; but when I travel by railway I must say I am glad on looking at the tender to find that the coal being used is of an anthracitic character, and to see there the smokeless Welsh coals, the highest class employed in steam navigation.

Various plans have been resorted to for smoke combustion, but they may practically be said to have settled down into the use of the 'Brick arch' and of the 'Deflector' shown at 'A' 'B' on the diagram (fig. 8). The brick arch 'A' extends backwards inside the fire-box from the tube plate for about two-thirds of the length of the fire-box, while it spans the whole width of that box. The deflector 'B,' a ∩-shaped wrought iron pipe, is either fixed in the fire-box as shown, or, more commonly, is a mere loose inverted scoop inserted into the fire-door opening. The deflector points towards the hinder end of the brick arch; and the combustible gases, be they carbonic oxide or the

smoky hydro-carbons, passing under the heated brick-work, are put into a highly favourable condition for combining with the oxygen of the air, which is introduced to them by means of the deflector, at the very point where they are curling round the end of the hot arch.

To complete this subject of the present practice in smoke prevention, I will call your attention to a ring pipe C, placed round about the blast pipe, and perforated on its upper side. This ring pipe can be supplied with steam direct from the boiler, to effect the combustion of the smoke at the time when the steam is shut off from the engines (as when standing at a station), for while the engine is standing the waste steam blast ceases, and there is therefore no active draught of air either through the fire or over the fire; frequently, in fact, the products of combustion escape at the fire-door, and if there be green coal at the top of the fire, the smoke becomes most offensive. To prevent this, the direct boiler steam is sent out of the ring pipe, and induces a current of air up the chimney, sufficient to enable the greater part of the smoke to be consumed.

I regret to say, however, that engine drivers, either from idleness or from a desire to economise the steam, very commonly fail to turn on this auxiliary blast in time, and sometimes do not turn it on at all; if, therefore, as is not unfrequently the case, they have selected the period immediately before arriving at a station to 'coal up,' the belching forth of black smoke is of the most offensive character. The ring jet is also useful in accelerating the first getting up of steam, as it can be put into operation as soon as a few pounds pressure are obtained.

In French locomotives, in virtue of a law to that effect, and in carefully constructed engines in our own country, there is placed across the widest part of the smoke box a grating, D, to arrest the passage of flakes

of lighted fuel, and to prevent their being ejected from the chimney. This is a very necessary precaution; but one that, I am sorry to say, is even now too commonly neglected by engineers, many of whom declare that it is impossible to work engines efficiently with such a grating, although engines on some of the most important lines have been running thus fitted for very nearly twenty years. An analogous precaution should also be taken at the ash-pan, by placing within the air-regulating dampers, gratings, which should be hinged so as to admit of being lifted when the ashes are cleared out—the danger at the ash-pan is, that large red-hot cinders may be jolted out, and then may be caught by the spokes of the wheels and be sent flying, as a cricket-bat sends a cricket-ball.

I will now pass away from the subject of the generation of heat by the combustion of fuel, and will go to that of the utilisation of the heat produced.

In order that the water shall absorb the heat given forth by the fuel, it is necessary that there should be a sufficient amount of surface which, as I said in the outset, is on the one side wetted by the water, and on the other licked by the flame.

This sufficient amount is obtained in the narrow compass of a locomotive boiler by resorting to the multitubular construction, a construction which enables a large, a thin, and yet a safe surface to be aggregated into an extremely small space. In such a locomotive as the goods engine before us, there will be as many as 230 tubes, $1\frac{3}{4}''$ diameter, $11'\ 8''$ long, containing therefore an aggregate surface of 1,240 ft. To this must be added the surfaces of the sides of the fire-box, amounting to about 110 ft., making together a total of 1,350 ft.

Taking the maximum rate of evaporation as being equal to, as we have said, 1,800 gallons of water per hour,

or 288 cubic ft. = 18,000 lbs. of water per hour, the total amount of surface, tube and fire-box together, employed in such a locomotive to evaporate a cubic foot of water per hour, will be found to be about 5 ft.

Those who are engaged in the practical working of engines, and indeed, in these days of newspaper reports, of steamboat trials, those who are not so engaged, are well aware of a boiler difficulty called 'Priming,' that is, the bringing over, mechanically suspended in the steam, of minute particles of water. When priming occurs, very unsatisfactory results are obtained. These are: first, the waste of fuel arising from parting (for no useful purpose) with water heated by the fuel up to the temperature of the steam; and second, the danger of straining the parts of the engine by its passages and clearance spaces becoming choked with water. It is therefore in the highest degree desirable that priming should be avoided as much as possible. This necessity, and that of making sure that the tube surface shall be thoroughly wetted, forbids the multiplication of the tubes, within a given size of boiler, beyond a certain point, for otherwise there would not be left between the tubes sufficient passage for the circulation of the water and for the ready escape of the steam. But even when these precautions are taken, it might be objected by an engineer conversant only with boilers such as were used for low pressure engines fifty years ago, that the weight of steam generated could not be liberated from the surface of the water in the boiler without disturbing the tranquillity of that surface and causing the ebullition which produces priming; and this objection would be true were it attempted to boil off the same weight of water per hour in a locomotive boiler under a pressure of, say 10 lbs. to the square inch, as is boiled off under a pressure of 120 or 140 lbs. The reason of this difference will, if one con-

siders, be found to be the variation in the relations between the bulks and the weights of the steam under the two supposed conditions. For example, if the weight of water turned into steam be represented by a given number of bubbles of steam produced in a given time, then, if the steam be at a low pressure, say of two atmospheres, these bubbles will each of them have a certain size; whereas, if the steam generated be at twelve atmospheres, the bubbles will only have one-sixth of the size; or if we put it, that whether the steam be at the lower pressure or at the higher one, the bubbles are always the same size, then, in the case of the lower pressure steam, they would be six times more numerous than in the case of the higher pressure steam. In either way of looking at it, it follows that the tranquillity of the surface of the water must be much more violently disturbed by the passage up through it of a given weight of steam of a low pressure, than by the same weight of steam at a high pressure.

Let me illustrate it in this way. Suppose that a pound of small shot were fired from a submerged gun pointing upwards, and that these shot were made of lead. Next suppose that a pound of shot from the same gun were fired, but that these shot were made of wood: it is quite certain that the pound of leaden shot would make their way upwards through the water with much less disturbance than would the pound of wooden shot, bearing in mind the vastly increased bulk in the case of the wood.

We now come to the question of the safety of the boiler.

With respect to the 'barrel' of the boiler (as it is called), that part which contains the tubes, the question is a simple one, as the barrel is a regular cylinder, and there is only demanded that this cylinder, which is sub-

jected to an internal bursting strain and to an endways strain, and to these strains alone should be made of adequate strength, as there is here no risk of deformation.

The front tube-plate—the flat plate at the smoke-box end—is, as regards its lower part, sufficiently stayed by the tubes themselves, and, at its upper part, is protected by longitudinal tie rods, which, extending the whole length as far as the back of the fire-box, assist in staying that back. In addition to these stays, others of a somewhat similar description are used between the lower part of the barrel and the back tube-plate. With respect to the fire-box, however, the question of safety is by no means so easy a one to satisfy, for in plan section the internal and external fire-boxes are rectangular, and we have, therefore, eight sides of the weakest possible form to protect against the pressure of the steam. This protection is effected by what are known as 'screw stays;' these stays are rods, usually of copper, placed at, say, $3\frac{3}{4}''$ to $4''$ apart, screwed through both plates and riveted over; it is in this way that the tendency to separation of the surfaces is overcome, but it must be confessed that the mastery is obtained by the exercise of that which may be looked upon as a species of brute force.

We now come to the roof of the fire-box, a very important part to stay, because in addition to its being a flat surface as are the sides, or a nearly flat surface, it is one which (if the water is suffered to get at all low) is liable to become red hot. Various plans have been proposed, and are in use for staying the roof. One, and a very common one, is to suspend the roof by means of bolts and nuts from a number of wrought iron girders, E bearing at their ends on the back and front plates of the internal fire-box (see fig. 10). When such girders are employed, they, coupled with the means already stated,

complete the staying of the boiler, the half round top of the external fire-box being competent to withstand the pressure without assistance from stays.

Another mode of staying the fire-box roof is shown in the separate diagram fig. 11, and in the diagram fig. 8, wherein stays, F, are taken from the roof of the internal box to that of the outer box; and this plan, which has

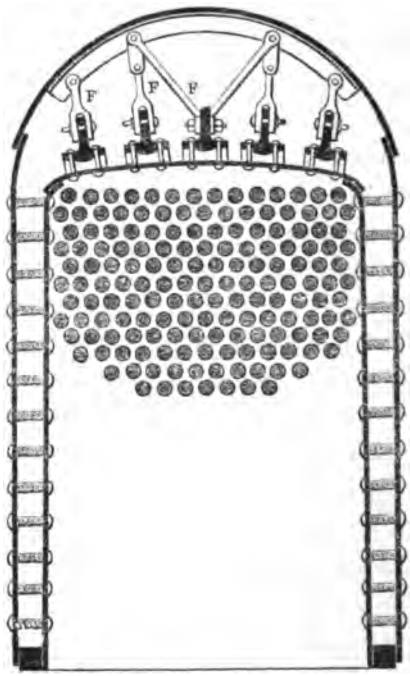


FIG. 11. Staying of fire-box.

long been known and used, is now being again received with considerable favour. It is said, however, that such a mode of staying the roof is likely to cause a gradual giving way of the side screw stays, and for the following reason: the downward pressure of the steam upon the roof of the internal fire-box is clearly conveyed by the suspending stays to the top of the external fire-box,

thereby putting upon it an unbalanced pressure. It might be said, on a first consideration, that the pressure is not unbalanced because there is the same force of steam upwards against the top of the external box as there is downwards on the roof of the internal box; but it will be

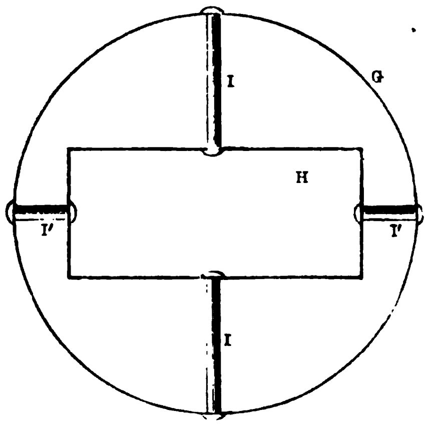


FIG. 12.

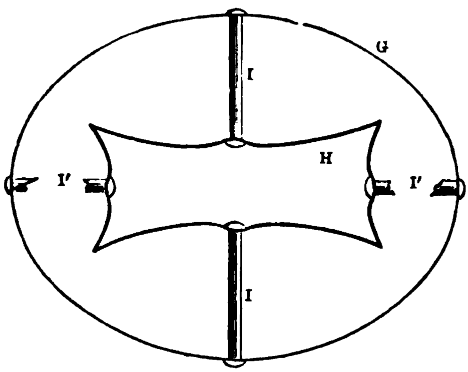


FIG. 12A.

found that this upward pressure is required to counterbalance the equivalent lateral pressure against the sides of the external fire-box, and that thus, the downward pressure, put on by the hanging stays, must be borne by the side screw stays.

Diagram 12 is intended to illustrate this question. Take the top figure to represent the section of a cylinder, G, having a flat rectangular chamber, H, in it, the top, bottom, and ends of that chamber being connected by stay rods, I I′, to the interior of the cylinder, and assume that there is a

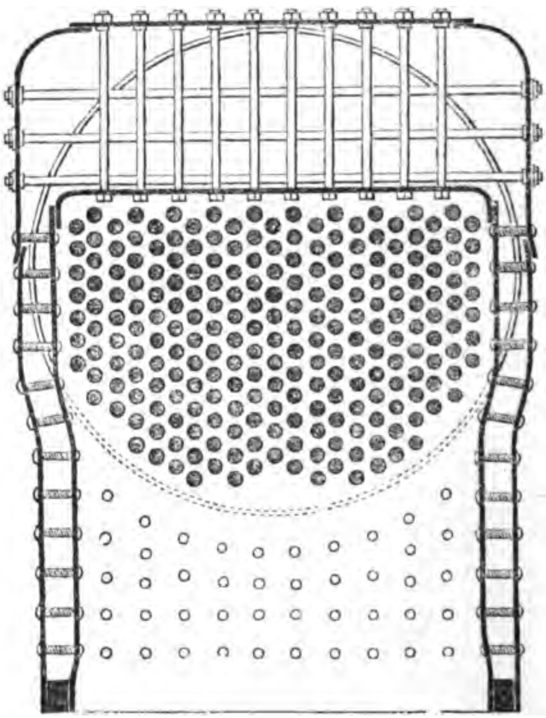


FIG. 13. Mode of staying French fire-box.

pressure, say of steam acting on the interior of the cylinder and on the exterior of the rectangular chamber, there being no pressure whatever within that chamber. The result of such an arrangement would obviously be to destroy the equilibrium of strains within the cylinder, and the tendency would be to the condition of things shown in the bottom figure 12A; where the broad top and bottom of

the rectangular chamber are driven together, distorting the cylinder into an ellipse and rupturing the side stays, I′. In practice, the case in the locomotive is not as bad as is here shown, because the roof stays are not all vertical, and those towards the sides being inclined reduce the amount

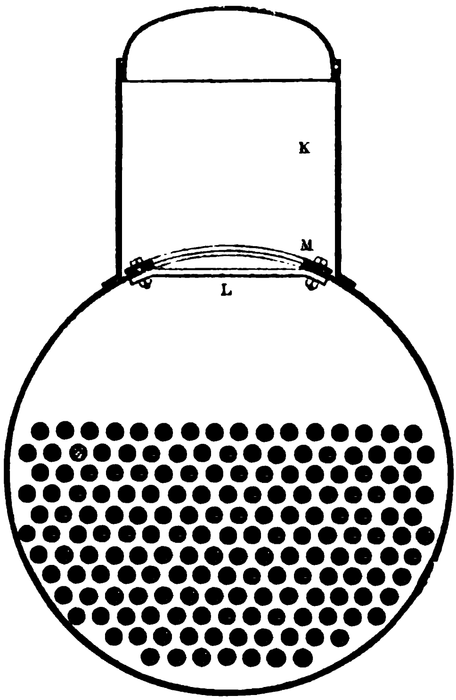


FIG. 14. Staying of steam chest.

of strain which would otherwise come upon the horizontal screw stays.

I am of opinion, that both the girder tays and the suspending stays are open to objection. To get rid of these objections the Belgians and, I believe, the French have introduced a class of fire-box (see fig. 13) wherein the outer shell is made rectangular, and wherein the horizontal staying of that shell therefore must be con-

tinued up to the very top, and then the top of the internal fire-box may be stayed, by pendent roof stays from the outer box, without any disturbance of the balance of pressures.

Very frequently locomotive boilers are furnished with steam chests, K (fig. 14). If a hole be made in the barrel the full size of the steam chest, obviously there is a large reduction in the strength of the barrel at that part. If (as is sometimes done) only a small hole be made, there is still a very considerable reduction, because, as will at once be seen, the pressures above and below the piece of plate at the bottom of the steam chest being equal, that plate can only operate to tie the barrel of the boiler together by the strength which it possesses as a stay-bar, for which purpose it is very unfitted, as it is of a curved form. The proper way to guard against loss of strength from the use of steam chests is to place strong straight bars, L, across the cavity, and to put a strengthening ring, M, for attachment of the bar ends (see fig. 14). This application of a strengthening ring surrounding a hole should be borne in mind wherever man-holes or other holes of considerable size are made.

The next element in the security of the boiler, and it is an important element, is the safety valve.

Looking at the high pressure employed and at the jolting of the engine as it runs along, a weighted valve would obviously be inadmissible, and, therefore, from the very early days, locomotive valves have been held down by springs. The common arrangement is to have a mere lever with a Salter's balance spring at the end, generally so graduated that the figures on the balance, after allowing for the leverage, the area, and the weight of the valve and lever, represent pounds on the square inch. Objections are urged against this valve (and other spring

valves) on several grounds. One is, that it can be interfered with by the driver, who may screw it down more and more; this, however, can always be guarded against by proper stops. Mr. Ramsbottom's simple arrangement, shown in diagram 15, overcomes this objection, and gets rid of any question of variation of pressure

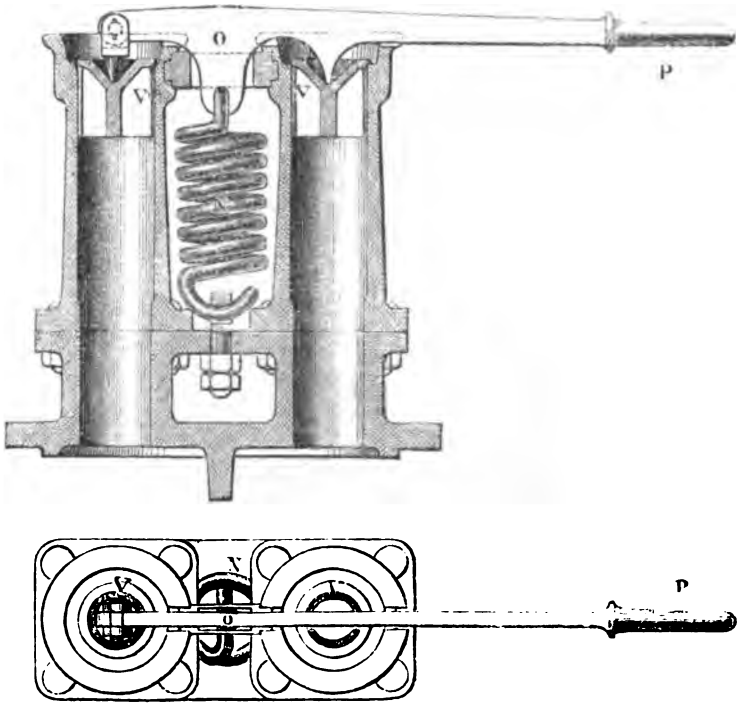


FIG. 15. Ramsbottom's safety valve.

produced by the act of the engine driver. Here it will be seen there is only a single central spring N, which holds down a pair of valves V V by means of a cross head O, one end of which is prolonged and formed into the handle P, through which either valve may be made the 'point d'appui' for opening the other valve by pressure, either upwards or downwards, as the case may be, upon the handle.

Another objection urged against spring valves applies

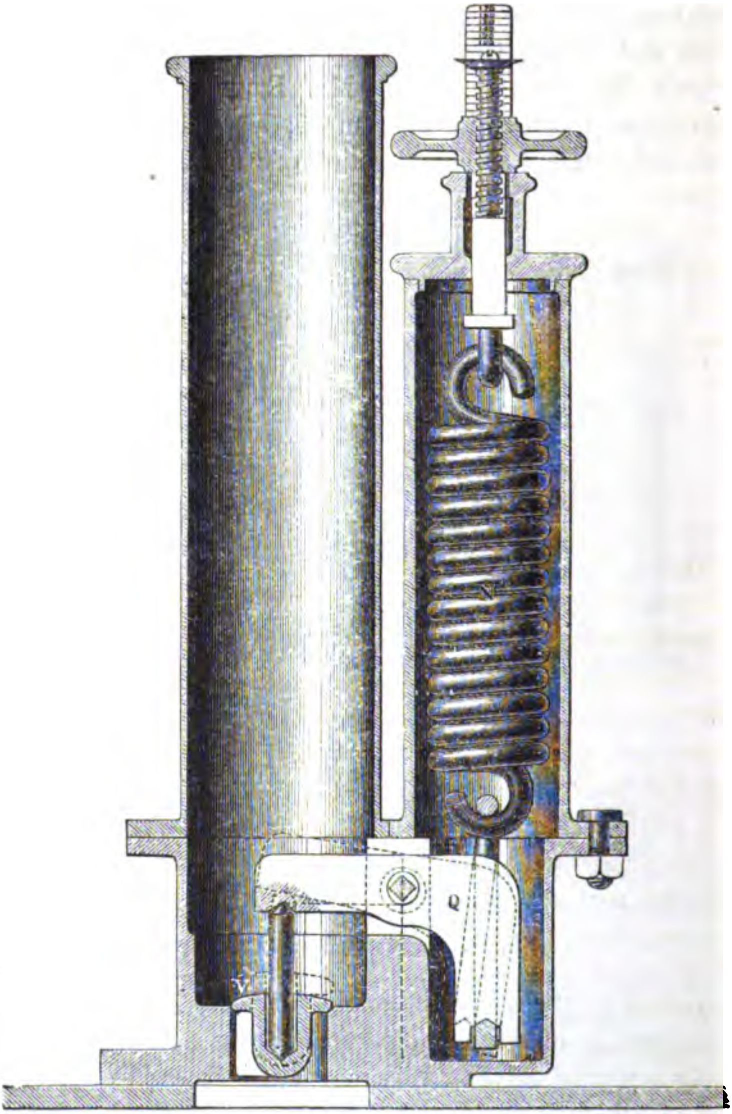


FIG. 16. Naylor's safety valve.

to Ramsbottom's arrangement as well as to the ordinary

Salter balance, and that is, the difficulty of obtaining an aperture sufficient to deliver a large quantity of steam, without at the same time materially increasing the pressure, because, obviously, as the valve rises the spring is distended or compressed, and thereby the load is increased, while there is good reason to believe that at the same time the effective pressure to act upon the underside of the valve is reduced. There are valves in use (fig. 16) which get rid of this head of objection, either by applying the pressure of the spring N through a lever Q, the angle of which varies as the valve rises, so as to give the spring, although further distended, no more effective pressure upon the valve V, or by so constructing the valve and seating (fig. 17) that, when the valve V lifts, a margin of the valve exterior to the steam-tight seating, shall come into play in aid of the lifting surface. Very satisfactory results have been obtained from both constructions. It must be borne in mind, however, that in the locomotive, which has its fire urged by the waste steam blast, there is the special advantage of an automatic cessation of the strong production of steam at

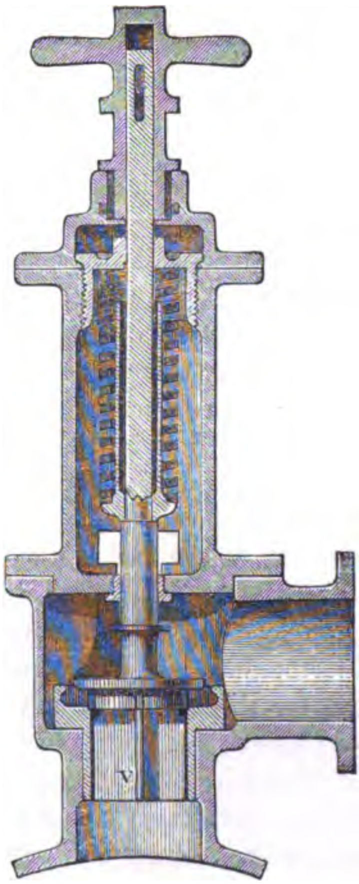


FIG. 17. Adams' safety valve.

the very moment that the demand for steam by the engines ceases; and thus the safety-valve question is not practically as difficult a one in locomotive, as it is in other boilers, where the fires have only a natural draught. Moreover, the careful locomotive driver can always prevent excess of pressure, and waste of steam at the safety valves, by directing the steam, which would otherwise blow off to waste in the air, into the water in the tender so as to heat it before it is fed into the boiler, or, when the engine is supplied with an injector, or with a donkey engine, by feeding into, and thus cooling the water in, the boiler while the engine is so standing.

The next point to consider in relation to the boiler is this very subject of supplying it with feed water.

Formerly this was done, as in the case of the boilers of all other engines, by means of a pump worked from the engine, and deriving its water from the tender; and had that been the only mode by which boilers are now filled, I should, in the sequence of my lectures, have reserved the question of the feed until describing the engine itself, of which the feed-pump forms a part; but of late years many more locomotive boilers are fed by means of the Giffard injector than are fed by pumps worked from the engines, and for this reason I think it will be well to take up the feed question at the present part of our lecture.

The injector is, to my mind, one of the most striking modern inventions connected with the steam engine, as by it an apparently insolvable problem is solved, the problem being no less than this, how, by means of the issuing of steam from a boiler, to impress upon a column of water a velocity so great that it shall enter the boiler from which the steam is issuing, and that the steam which has issued, shall return into the boiler from which it came out, not as steam, it is true, but as water.

I have hung on the wall a diagram (fig. 18) of a vertical section through an injector, and, thanks to the kindness of Messrs. Sharp, Stewart, & Co., I am enabled to show you a section of an actual injector.

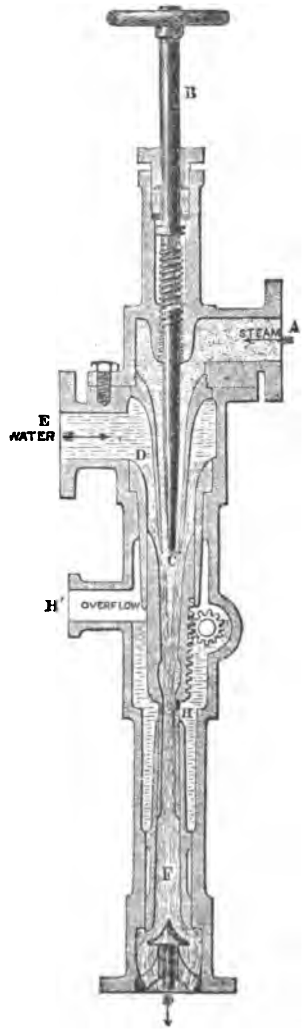


FIG. 18. Giffard's injector.

You will see that the steam from the boiler enters the instrument by the pipe A, and that it passes around the outside of a long conical pointed spindle B, by varying the endway position of which the steam may be regulated in its flow from the orifice at C. The orifice C is in the middle of an annular space D, to which space the water to be fed into the boiler is introduced by the pipe E. The steam, escaping with high velocity from the orifice C, induces a current in the water which is in the space D, and carries it forward at the less velocity corresponding to the increased weight of the combined stream of water and steam, but still at a high velocity. The steam being condensed by contact with the water, unites with it, and forms a part of the forward-rushing stream. This stream is received into an expanding channel F, where its velocity is gradually lost; and from this channel the stream passes into the boiler, opening on its road a stop-

back valve, which closes to prevent the water escaping from the boiler when the injector is not at work.

To enable the jet to get a fair start, an overflow is provided by the escape orifice H, and overflow pipe H′. In the injectors as now made and exhibited before you, there is a regulation of the feed-water by means of the rack and pinion, through the operation of which the receiving nozzle can be moved bodily endways, so as to vary the amount of annular opening where the feed-water comes into contact with the steam jet.

I will now, if you will permit me, give a very unscientific, but, as it appears to me, a very intelligible explanation of the principle of action of the injector, an explanation which I ventured to put forward when the injector was a novelty, and a novelty so startling that most engineers refused to believe in the statements made as to its powers. To enable my explanation to be more readily followed, let me ask your attention to the diagram (fig. 19) to which I now point. I have shown there two cisterns A and B. Imagine A to be nearly full of water and B to be empty; imagine, further, that a jet issues from a hole in one of the sides of A, and not much above the bottom of it, and that this jet is aimed at a hole D, situated in a corresponding position in one of the sides of the empty tank B. We know that the jet would enter B, and we also know that it would continue to enter long after the water in B had risen to a considerable extent above the orifice: in fact, friction apart, it would, as Mr. Froude has shown us, be possible by a due shaping of the receiving aperture to enable the jet to enter until the water in B rose to the height of that in A; but it is sufficient for my purpose to be content with much less than this. I will suppose, for example, that the inflow would cease when the water in B had risen to the height shown by, say, the dotted line $x\,y$.

Now, if under these circumstances I desired to continue the inflow of the jet, how could this be accomplished? It clearly could be done if I could perform the feat of turning the jet of water, in its passage across from A to B, into a jet of mercury having the same weight as that of the water jet, and having the same velocity. I have drawn (see fig. 19A)

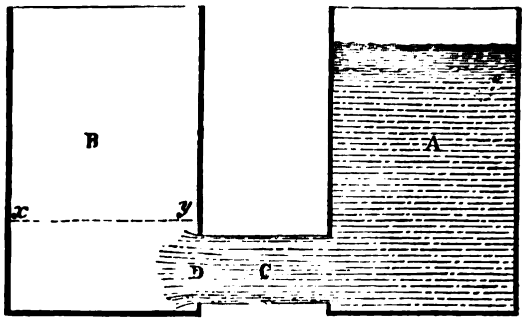


FIG. 19.

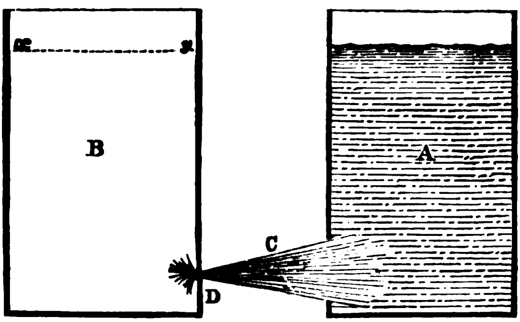


FIG. 19A.

a second jet, where I assume this change to take place: the result must be, as shown, to diminish the area of the entering jet exactly in the relation of the density of mercury as compared with that of water. Call this relation fourteen to one. If this change could be effected, it is obvious that the whole energy of the jet proceeding from an orifice of an area of, say 1, in the side of the tank A, would be delivered

Z

into the tank B through an orifice of only $\frac{1}{14}$ in area; thus there would be a concentration of the energy of the jet which had issued from an area of 1 into an area of only this $\frac{1}{14}$ part of the size, and this concentration of energy per unit of surface, would clearly suffice to overcome a far greater head than that which would prevail in tank B, even when filled to the height of A, and therefore it would be possible for the jet when turned into mercury to re-enter the tank A, from which as water it had set out.

Now, although we cannot perform the feat of turning water into mercury, and thereby diminish the area of a given weight of jet to $\frac{1}{14}$ of that which it had as water, we can convert a jet of steam into water; and if that could be done by the application of cold surfaces, we might diminish the area of the jet to $\frac{1}{1700}$, or $\frac{1}{800}$, or $\frac{1}{400}$, as the case might be, depending on the pressure of the steam and on the density as compared with water due to that particular pressure. To obtain such concentrations as these would doubtless not be practicable, because it would involve, as I have said, the condensation of the steam in its brief passage between the outlet and the inlet orifices, by some application of external cold, which should be capable of abstracting the heat with sufficient rapidity, but should not mingle with the water. Moreover, if this could be accomplished there would be no useful result, as the only thing that would be attained would be the return into the boiler of the same weight of water, as that of the steam which had issued from it, with the loss, however, of the whole heat of conversion of the water into steam, which heat would have been uselessly transmitted to the cooling medium.

Let us now go to the practicable mode of converting the steam into water in the brief time allowed for the

operation; that mode is, the mingling together of the cooling water and of the steam to be cooled; in this way the conversion of steam into water can, and does, take place. The jet of condensed steam, however, will no longer be of the diminished area of $\frac{1}{1700}$th, $\frac{1}{800}$th, $\frac{1}{400}$th, or whatever else may be the relation between the density of water and that of the steam which has been condensed, because there must be added to it the weight and bulk of the water producing the condensation; but even after allowing for this, the concentration will still be very great; say, for example, that the weight of water used is nine times the weight of steam, the resulting jet would still have a concentration of $\frac{1}{170}$th, $\frac{1}{80}$th, or $\frac{1}{40}$th, as the case might be, enough and more than enough to enable the combined stream of condensing water, *i.e.* the feed-water, and of the condensed steam to enter the boiler from which the steam had issued. According to my view you will see the principle of action of the injector can be expressed in one word—the word I have used so frequently in my explanation of the action of the injector—'concentration,' and I may, perhaps, be permitted to say that I have employed elsewhere the same word to express the principle in which lies the destructive effect of a 'Palliser' or other pointed hard projectile.

Locomotive boilers are also supplied with water, as I have mentioned, by means of feed-pumps. One is shown at R in the outside view of the passenger engine (fig. 9), worked off the crosshead of the piston, and possessing, therefore, the full stroke of the piston.

Another mode of working the feed-pumps from the engine itself, but one very rarely employed now-a-days (indeed, as I have said, feed-pumps are the exception now), is to have the pump plunger of large area, and to work it at a slow velocity off an eccentric, or off a crank pin.

I am very much tempted to go into the question of the proportioning of pipes and valves for these pumps to ensure accurate and regular working, but I must refrain, looking upon such questions as partaking too much of the nature of practical detail to be entered into in these lectures.

The third mode of feeding a locomotive boiler is by means of a donkey engine. One of these is shown at s′ in elevation on the passenger locomotive (fig. 9). The donkey is rarely resorted to for regular work, but is at hand as a stand-bye to be put into operation on an emergency.

It may be interesting to remark that, for many years before the invention of the injector, donkeys were not employed, and that thus, in the absence both of donkey and of injector, there was no mode of feeding a locomotive except by running it along the line and putting its main engines into operation, and when an engine had finished its work of drawing trains and happened to be short of water, it was not an unfrequent or an uncommon thing to see it running backwards and forwards on a siding to feed its boiler. But this mode became so objectionable, as the lines became more and more crowded, that recourse was had to the complicated arrangement of cutting the rails of a 'siding' and of introducing, into the space, the peripheries of loose wheels, so that the engine might be driven over them, and then, its driving wheels being caused to bear exactly on the tops of the loose wheels in the line of railway, the engine on being put to work no longer propelled itself along the line, but simply turned the supporting wheels, and thus enabled the pumping to take place without the engine running backwards and forwards. It is a curious reflection that, for many years after donkey engines were in common use for feeding marine boilers, no better mode occurred to the railway engineer of obtaining that end

than the cumbrous one to which I have just alluded. At length, however, donkey engines were used, and then came the injector, which, as it possesses no moving parts, and may be worked without the aid of the engine, is, as I have said, generally used (in stopping trains) when the driver is careful, at the very time when the locomotive is not under way.

LECTURE II.

SELF-FILLING TENDER — STEAM CYLINDERS — PISTONS — CRANKS — AXLES — WHEELS — TYRES — INDICATOR — SLIDE VALVE — LINK MOTION — REVERSAL.

We concluded our last lecture by a description of the various modes which have been employed for feeding the boiler: I will now say a word or two respecting the place whence the feed water comes.

You have before you diagrams of three engines: one, of a tank engine, carrying its own water, the others of two engines, each demanding the addition of a tender.

Time does not admit of my entering into any description of tenders beyond saying, that they are four or six-wheeled carriages supporting tanks, containing from 1,600 to 2,500 gallons (or even more) of water, and having places for the reception of the fuel; and that, almost invariably, they are fitted with brakes, for which purpose their great weight renders them very suitable.

The ordinary mode of putting water into the tender is by means of the well-known water crane; but I wish to call your attention to another mode invented a good many years ago by Mr. Ramsbottom, to whose arrangement of safety valve I have already alluded.

By the kindness of Mr. Ramsbottom, I am enabled to show you a model of a tender fitted with his apparatus, and I have hung a diagram (fig. 20) of this upon the wall.

The object of the invention is that water may be taken up while the train is in motion; this is a very desirable thing in the case of express trains, such as the Holyhead Mail, where every minute is of consequence,

and a very desirable thing also in the case of slow trains, travelling on a portion of line (such as that between Manchester and Liverpool) where, from its thronged condition, stoppages should be reduced as far as possible.

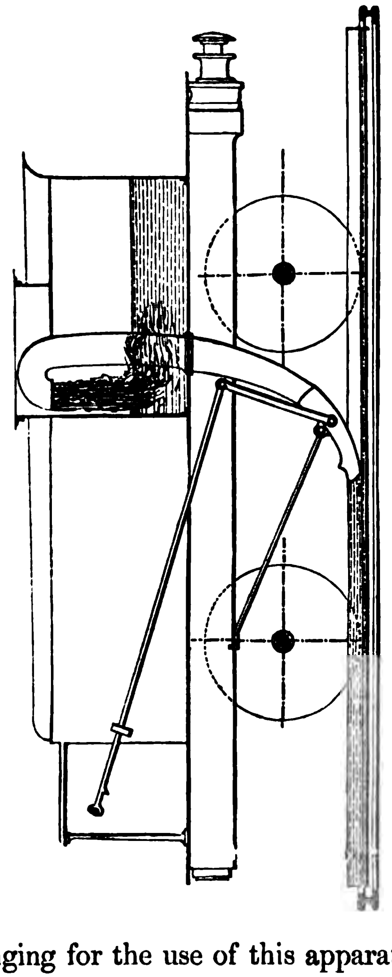


Fig. 20. Ramsbottom's self-filling tender.

In arranging for the use of this apparatus, a perfectly level portion of the line is selected, and here there is laid, between the two rails of each line, an open-topped trough, of about a quarter of a mile in length.

This trough is kept filled with water from some neighbouring source of supply, and the tender, as you will see, is fitted with a curved pipe projecting forwards and downwards, so that its mouth may dip into the water. As the train goes along the water mounts the curved pipe and overflows at the top into the tender, filling it up to the desired point: in this manner 2,000 gallons of water may be delivered into a tender in less than one-third of a minute. The pipe has a joint in it, so that it can be raised when the engine is not over the trough, and lowered when it is. It may perhaps occur to you that there would be a risk of the driver not lowering the pipe, and of his not raising it again, at the proper times, and that thus a portion of the length of the trough might not be utilised while the engine was passing over it; and also, that if the pipe were not raised in time, or were lowered too soon, the ends of the trough might be knocked out, or the pipe might be broken. But this difficulty is guarded against by a very simple but ingenious arrangement. At the ends of the trough the rails are raised a few inches above the general level, there being an incline on each side of the raised point, leading up to it, and down again—that is to say, there is a gentle hill in the rails opposite each end of the trough. You will see, therefore, that it is perfectly possible for the pendant pipe to be lowered before the engine arrives at the trough. The hill raises the pipe so as to carry it clear over the trough end, and then the tender running down the hill plunges the mouth of the pipe into the trough, it may continue unlifted during the entire passage of the tender over the trough, and beyond its further end; because the second hill again raises the pipe, and enables it to escape above the closing end of the trough.

Having now dealt with the subjects of the generation of steam, the feeding of the boiler and the provision of

water, we may profitably consider the engine which utilises the steam that is generated.

In ordinary locomotives there are always two complete engines coupled to one shaft, and these engines (as I have already said) operate upon the driving axle directly, without the intervention of gearing. The steam cylinders may be taken as ranging from 14 in. to 19 in. in diameter of bore, and the piston stroke as varying from 20 in. to 28 in.

The parts of a direct-acting steam engine are few and simple; they comprise the truly bored cylinder, within which the piston moves backwards and forwards under the alternating reversed pressures of the steam; attached to the piston is the piston rod, issuing steam-tight through a stuffing box in the cover of the cylinder; this rod carries at its hinder end a head or crosshead, from which proceeds the connecting rod, that in union with the crank converts the reciprocating motion of the piston into the rotary motion of the crank shaft. To these parts must be added the guide block at the piston-rod head; this block prevents the resolution of the force transmitted by the connecting rod (while it lies at an angle) from deflecting the piston rod, which it would do were not some species of guide provided. The only remaining parts are those of the apparatus which admits the steam alternately on each side of the piston, and also permits the steam which is being used to exhaust alternately, from each side of the piston, and to find its way up the blast pipe into the atmosphere, or to the feed-water tank.

In designing the engine of a locomotive the first question to be answered is, Where shall the cylinders be placed? 'Inside,' that is to say, between the two wheels of a pair, as in the goods engine (fig. 8), or 'outside,' that is to say, exterior (so far as regards the centre lines of the cylinders) of the two wheels of a pair. The temptations to

put the cylinders inside are these: they are well secured to the framing, they are kept hot in the smoke-box, there is an excellent fastening for the ends of the guide rods, and the connecting rods are so placed that they do not interfere with the crank-pins by which two or more pairs of wheels are coupled together. Moreover, the ports between the slide facing and the body of the cylinder are very short. It is also urged as one great reason for using 'inside' cylinders, that the engine must be more steady in running than when the alternating pressures are applied at a greater distance from the centre line of the machine, as they are when the cylinders are 'outside.'

The objections to putting the cylinders 'inside' are, that in powerful engines, where the parts are large, there is of necessity much crowding, because it is impossible to widen the space between the wheels. Other objections, and very great ones, are the first expense, the risk of fracture, and the large friction, involved in the cranked axle.

Outside cylinders have the advantages of working on to a crank-pin carried in one of the wheels (the axle in that case being a mere plain forging), and also of leaving ample space within the framing for the valve gear; but they possess the disadvantages of making some complication where wheels have to be coupled together, of being away from the heat of the smoke-box, and of having a very long steam passage, or port, between the cylinder and the slide facing, unless, indeed, the slides be worked through the intervention of 'way shafts,' a practice which is rarely resorted to in new engines.

With respect to the opinion at one time, and, I believe, even to the present day prevalent, that the placing of the cylinders 'outside,' that is, far from the centre line of the

locomotive, must cause a greater oscillatory motion than is caused when the cylinders are inside, I think I may appeal to practice to contradict this impression, and I will also refer you to my own observations in the twenty-second volume of the 'Minutes of Proceedings of the Institution of Civil Engineers' upon this point.

I have incidentally mentioned the use of a 'way shaft.' I ought, perhaps, to have said that this is the technical name for an oscillating shaft which is worked by a lever, actuated by an eccentric rod, and carrying another lever that works the slide valve; but the desirability of reducing the number of parts as far as possible has caused engineers to dispense with 'way shafts,' and to substitute a direct attachment to the slide valve stalk; and unless the very unusual construction of placing the eccentrics externally upon a 'return crank' be employed, this direct attachment involves the slide valves being placed within the framing.

With inside cylinders it became extremely difficult, as engines increased in dimensions, to find room for the two slide valves and the two chests in which they worked. This difficulty speedily led to the use of a single steam chest, between the two cylinders, and common to the two slide valves of those cylinders: thus space was saved, but as the cylinders became larger and larger, this remedy no longer sufficed, and it has been necessary to alter the position of the valves, and sometimes even to have the centre lines of their stalks lying at a considerable angle with the centre line of the cylinders; or as in the example before you, the goods engine, you will see that the slide valves are inverted, and are placed immediately below the cylinders. With the outside cylinder engine, as I have said, this difficulty of finding room for the slide valves does not exist.

Coming now to the parts of an engine; whether it be 'inside' or 'outside,' we have the cylinder provided with suitable brackets for attachment, and also provided with two covers; the one at the back end commonly cast on, and having a stuffing box and gland through which the piston-rod passes; the other at the front end secured by bolts so that upon its removal the piston can be extracted. Cast upon the side of the cylinder is the slide facing, containing the central exhaust port, and on each side of this a steam port, leading by steam passages to the front and back ends of the cylinder respectively. Over this facing works the slide valve, by which steam is admitted alternately to the two ends of the cylinder, and is alternately exhausted; about this I shall have very much to say, as upon the due proportion and adjustment of the slide valve depends the smoothness in working, and also the economy in working of the engine. The piston is made steam-tight against the side of the cylinder by elastic metallic packing. Many kinds of metallic pistons are in use, but I know of none so good, for locomotive purposes, as that simple one invented by Mr. Ramsbottom, which bears his name, and which consists merely of a few grooves (three commonly), turned in the piston body, into which are sprung pieces of D-shaped wire (for the rings are little more), which press outwards against the interior of the cylinder, and bear upon it with steam-tight contact. It is of course desirable that while the piston should move steam-tight in the cylinder it should also move with the least possible friction. Formerly it was the practice to make broad piston rings, rings the aggregate width of which would probably equal 2½ inches: these are now replaced by Ramsbotton rings, equal, on the whole, to but one inch wide. In order that a piston may be safe against leakage it is necessary that the ring should bear upon

the cylinder with a pressure at least equal to that of the maximum force of steam within the cylinder, because if this condition be departed from, and if steam leak in at any part between the surface of the ring and the interior of the cylinder it will press upon the ring, drive it backwards, and will pass on; but this pressure is a pressure per inch of surface, therefore the less surface there is in contact, the less will be the actual pressure, and the less therefore will be the actual friction; obviously, for these reasons, it is desirable to diminish the width of the bearing surface of the rings as much as possible in practice, and that it is which is done in the Ramsbottom piston. Moreover, the use of such a piston diminishes the wear upon the cylinder, while the wear of the rings is unimportant, as although they may require frequent renewal, say every six months, their total cost, even in a large locomotive, is only a few shillings.

Piston-rods are commonly made of mild steel, and are about one-sixth of the diameter of the piston. The piston-rod cross head is commonly guided either by a pair of bars on each side, having blocks within them, or by a bar at top and another at bottom, with a central block; the area of the guiding surface in contact is in practice made about one-fifth of the area of the piston. In large engines there is a difficulty here again in finding room for guide bars of either of the constructions mentioned, and you will see that in the goods engine (fig. 8) there is only a single guide bar, which is above the piston-rod, and which is embraced by the guide block. For the purpose of obtaining sufficient surface the guide bars are occasionally made with a series of steps, and the guide block with a corresponding series of steps, and thus the requisite area is obtained.

In the case of 'inside' cylinder engines, where a

cranked axle is used, the crank pin has, in order to transmit the torsional strain, to be as large as the main bearings, and thus no question of sufficiency of surface arises, but in outside cylinder engines, where the sufficiency of surface is the guide to the dimensions of the pin, it is commonly made of a diameter equal to one-fourth the diameter of the piston. The length of the connecting rod varies from about 2½ to about 4 times that of the stroke. Reverting to the cranked axle, this has to support its share of the weight of the machine, to bear the torsional strain of the engine, and also has to resist, as a girder, lateral deflection under the strain of the engines. For a 15-inch cylinder engine of 24-inch stroke the size of the crank axle in practice may be taken as 6 inches diameter and 12 inches long in the bearing. For an 18-inch goods engine 26-inch stroke, the axle in practice may be taken as 6½ inches diameter by 13 inches long in the bearing. In the first case, after deducting the weight of the wheels and axles, which weight is borne directly by the rail, the dead load to be supported on each bearing may be taken at 7 tons, and in the second case at 8 tons, giving a pressure of about 2 hundredweight per superficial inch, attained by multiplying the length of the bearing by its diameter.

This is an appropriate time to direct your attention to that which appears to be a very minor point in construction, but which is in reality a very important one—I mean the avoidance of all abrupt changes of shape. For example, if a shaft be made with a bearing, and an enlargement on each side of that bearing (which enlargements prevent endway movement), and if the shoulder where the enlargements occur be made perfectly square (as shown on the upper part in fig. 21), that shaft, whatever may be its dimensions, and however sound and good

its material may be, will give way at those shoulders, after having done but very little work, whereas, if the sharp corners be replaced by easy curves (as shown on the lower part of fig. 21), that shaft may continue to work without failure. The great cause of the breakage of the crank shafts of locomotives is the abrupt changes of dimensions, due no doubt to the difficulty there is in sufficiently easing off these abrupt changes. The ordinary points of rupture are at the junction of the throw, as it is technically called, that is, the side of the crank, with the shaft, or with the crank-pin. The fractures do not take place all at once, but begin by minute cracks, which extend, and extend, until a point is reached when the metal is too weak to resist some shock or jolt, and thereupon the remainder is broken through suddenly. At the outset these cracks are minute, so extremely minute, as to be invisible to the unaided eye, and are, in fact, somewhat difficult of detection even with a powerful hand glass. I may here perhaps be permitted to give you a useful practical hint as to the detection of such cracks in their earliest stages.

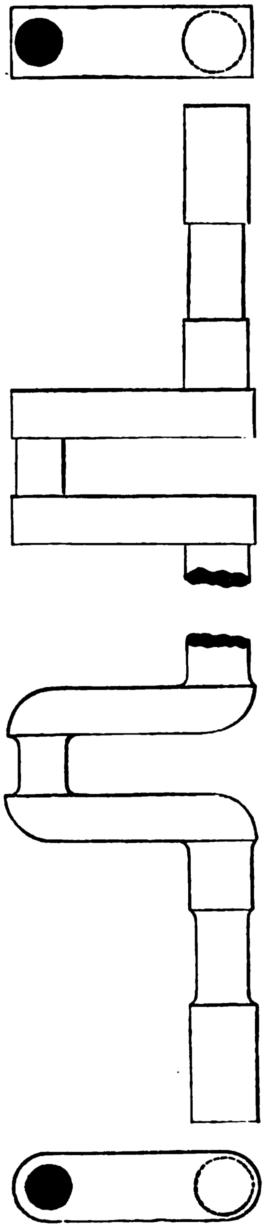


Fig. 21.

Many years ago, a railway com-

pany had suffered from the breakage of several cranked axles; these were all of one form, made by one maker, and of one material; the company had other axles of the same kind, which had not given way, and they determined to make a strict investigation, to ascertain whether there were any signs of failure in these. In some of the axles these signs were obvious, but there were others where, in spite of examination, no flaw could be detected. I was present at the inspection, and knowing, as in fact we all did, that when the final fracture takes place, the surface shows that the part of the metal which has not been broken at that final fracture, is stained with the dirty oil which has worked into the minute cracks, I suggested a mode of determining whether or not such cracks had commenced. This mode proved to be thoroughly successful, as it has been in every instance where I have applied it. We put the axle upon trestles, and, after having wiped the surface of the suspected parts (that is, the neighbourhood of the junction of the crank shaft, or of the crank pin with the throw) perfectly clean, we beat upon the end of the axle with a heavy hammer, so as to set up a vibration in the axle. When this was done, at one or two of the points of junction to which I have alluded, there was found a beautifully minute black line, as fine a line as could have been made with the finest drawing pen. These lines we printed off by the application of paper. The axle was again wiped, and an examination made; the cracks, however, were pronounced by many not to be cracks, but to be the marks of a 'scriber;' but the experiment was repeated, and the result was reproduced, although to a somewhat diminished extent. Subsequently I applied the same test to the crank shaft of an engine, which the owner had thrown out of use, believing it was injured, but which the engine builder refused to take back, alleging that it was sound. This

shaft had been out of work for more than twelve months before I was asked to examine it, and it had been lying in an unheated warehouse. Thinking that the length of time that had elapsed, and the cold condition of the shaft, might interfere with the success of the experiment, I had it gently warmed, and then applied the test I have mentioned, and with similar successful results. On another occasion I tested, while in its bearings, the very heavy crank shaft of a large stationary engine, a crank shaft laden with several tons of spur wheels, which it would have caused great expense and delay to have removed, and although I was somewhat doubtful as to whether, under these circumstances, the requisite vibration would be set up, I found the test was satisfactory, for in that instance also I got perfectly trustworthy indications of incipient flaw. I have already referred you to some remarks of mine at the Institution of Civil Engineers upon the internal disturbances in locomotives, and I must now, I am afraid, again give you a reference to other observations of mine. There is a paper published *in extenso* in the 'Transactions of the Sections of the British Association' for the year 1869, page 422, on the 'Influence of Form on Strength,' wherein I endeavoured, in a popular way, to show, why it is, that the neighbourhood of a large section to a small one, renders the small one weaker than it would be if there were no large one adjoining it.

The frames or skeletons of the wheels of locomotives are in England always made of wrought-iron forgings. The mode of manufacture is interesting, but I feel I have not time to go into it. In the skeletons are also forged, where necessary, the bosses to take crank pins and the counter weights to keep the engine in balance, to which matters I shall have to allude more fully. I may here, however, state that the question of balancing is a very

essential one, and that it has led Mr. Webb, the well-known locomotive engineer, of the London and North-Western Railway, to devise a special and very ingenious tool for the purpose of shaping the interior of the rim of the skeleton, so as to ensure that this rim should be of uniform section and weight throughout (fig. 22).

The tyres of the wheels require to be either of the very best make of iron, such as the first-class Yorkshire irons, or (and much more commonly now) of an excellent quality of steel; you will remember it is upon the exterior surfaces of the rims of these tyres that the heavy rolling work,

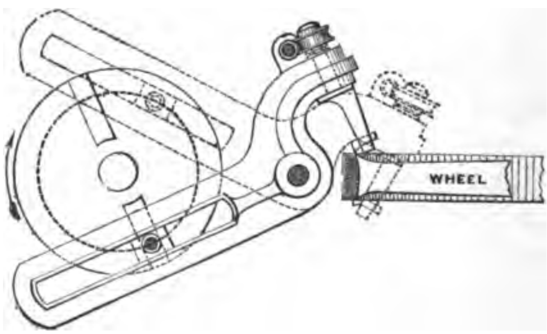


Fig. 22. Webb's shaping tool.

produced by the weight of the engine and by the traction, is taken. In former days, railway wheel tyres were rolled in straight bars, as rails are, and were then bent into a hoop and the ends welded, so as to form a complete ring. With every pains that can be taken, a weld is after all unsatisfactory. Some years ago the process of making the 'pile,' from which the tyre is formed in a ring, and welding it in that form, in the manner in which gun coils are now made and welded, was introduced. Large steel tyres are produced without welds, either by being cast in the ring-form and subsequently hammered and rolled, or, more commonly, by the perforation of a cheese-shaped

forging, and the enlargement by hammering or rolling of the thick ring thus made. The attachment of the tyre to the wheel frame is effected by accurately turning the frame and boring the tyre, so that it is somewhat smaller than the frame, and then by heating the tyre and shrinking it on; bolts being inserted from the inside of the frame, and tapped a short distance into the tyre to hold it, in the event of fracture (fig. 23).

In my judgment this process of shrinking is altogether unsatisfactory, although it is practically the universal process. It has been derived, no doubt, from the old plan of shrinking an iron tyre on to a wooden wheel, but the circumstances in the two cases are very different: not only is wood elastic, but the frames of wooden wheels are 'dished,' so that on the pressure of the tyre being applied, the cone formed by the spokes becomes more acute, and allows the felloes of the rim to yield sufficiently under the pressure, while the spokes by their elasticity preserve a proper tightness of the felloes against the inside of the tyre. But in the case of the wrought-iron skeleton of the railway wheel, the circumstances, as I have said, are very different; the frame is rigid, and, therefore, the question of shrinking on is one of extreme nicety. If enough shrinkage is not allowed, the tyre speedily becomes loose; if on the other hand too much is provided, there is great liability to fracture.

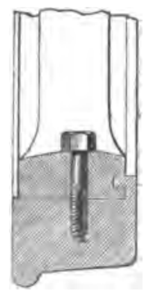


FIG. 23. Tyre.

The late Mr. William Bridges Adams, the inventor of the fish joint on railways (and a most original thinker in mechanical matters), proposed that the tyre should be loose upon the wheel, that it should be retained by proper arrangements, and that there should be an elastic medium between the tyre and the wheel (fig. 24). This

proposition was experimentally put into practice, and, I believe, with satisfactory results. This being so, it may

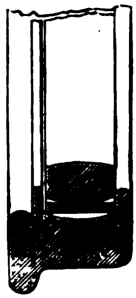


Fig. 24. Adams' tyre.

be a matter of surprise that the invention has not come into use, but the plan was bold and startling, and one should not complain that those who are charged with the safety of railways (as are locomotive superintendents) are chary of introducing novelties which cannot be thoroughly tested except by experiment in actual work; such experiment involving as it does the risk of serious damage, of interruption to traffic, and, although these novelties may not be tried on passenger trains, even loss of life itself. But allowing that for the present we must be content to shrink on our tyres (and I frankly admit that I should not dare to specify the construction of a wheel in any other way), I do not think that the use of screws (as shown in fig. 23) for the purpose of holding on the tyre if fractured should be continued. They weaken the tyre in the places where they occur, they weaken the frame in the places where they occur, and they are very liable to yield if fracture does take place, and to allow the end of the tyre to protrude and the tyre to be stripped off. These objections to screw or rivet fastenings are so well known that for many years past they have, as regards carriage wheels, been superseded on our best lines by safety rings. One mode of dispensing with bolts in engine wheels is shown in the diagram (fig. 25). In this construction you will see that the tyre is grooved all round on one side, and that it has a ring on the other side having a turned lip, engaging in a groove in the skeleton, thereby holding on the tyre at every

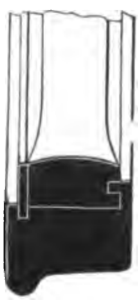


Fig. 25. Wrought-iron wheel with safety rings to tyre.

point of its circumference, and without any local weakening; but for years, although, as has been said, safety rings were applied to the carriage wheels, they were not applied to those most important of all wheels, *i.e.* those of the engine. For some time past, I am glad to say, however, fastenings of this kind have come into use for engine wheels.

Fig. 26 shows the rings applied, in conjunction with a wooden centre, to the tyres of carriage wheels; whereas

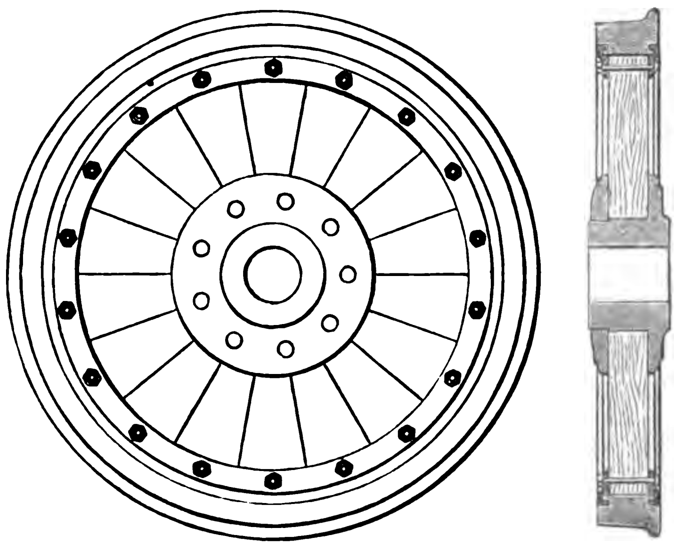


FIG. 26. Mansell's railway wheel.

fig. 25 shows, as I have said, the application of somewhat similar rings to a wrought-iron centre or skeleton, and that mode is therefore applicable to engine wheels.

I now revert to the question of the slide valve, and of the modes of working this, so as to procure the control of the speed and of the reversal of the direction of motion, and also so as to secure expansion; and I propose to devote a very considerable part of our time to the investigation of this subject, because on its being

rightly understood and rightly applied depend, as I have said, the smooth working of the engine, and also its economy in fuel. I will begin with an elementary slide valve, one that would admit steam throughout the whole of the stroke, and that would permit of exhaust throughout the whole of the stroke, a valve which would produce that kind of indicator diagram which is technically known as a square card (fig. 27). You are no doubt aware that in the earlier indicators, in Watt's indicator, for instance, the diagram was taken upon a flat surface, which had a horizontal movement imparted to it, derived by reduction from the stroke of the piston, while the pencil which traced the

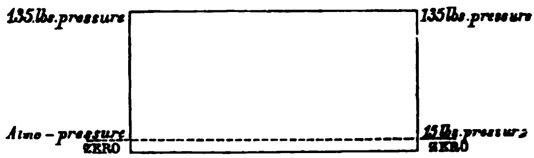


FIG. 27. Square 'card.'

figure had a vertical movement derived from the pressure of the steam as shown in fig. 28. This flat surface was a card, and thus, although now the card is replaced by a piece of paper wound round a cylinder, as in Richards' indicator (the one now in general use, see fig. 29), the word 'card' is still employed.

Diagram fig. 30 shows a slide facing, with the port *a* leading to, say, the left-hand end of the cylinder, the port *b* leading to the right-hand end, the port *c* being the exhaust. Above these ports there is a slide valve *d*, which, when placed in the middle of its journey, is just long enough to cover the two ports *a* and *b*, while the cavity in its interior is just long enough to cover the central exhaust port *c* and the two bars of metal between *c a* and *c b*; *m* is the crank shaft, with the crank pin *n*, at right angles

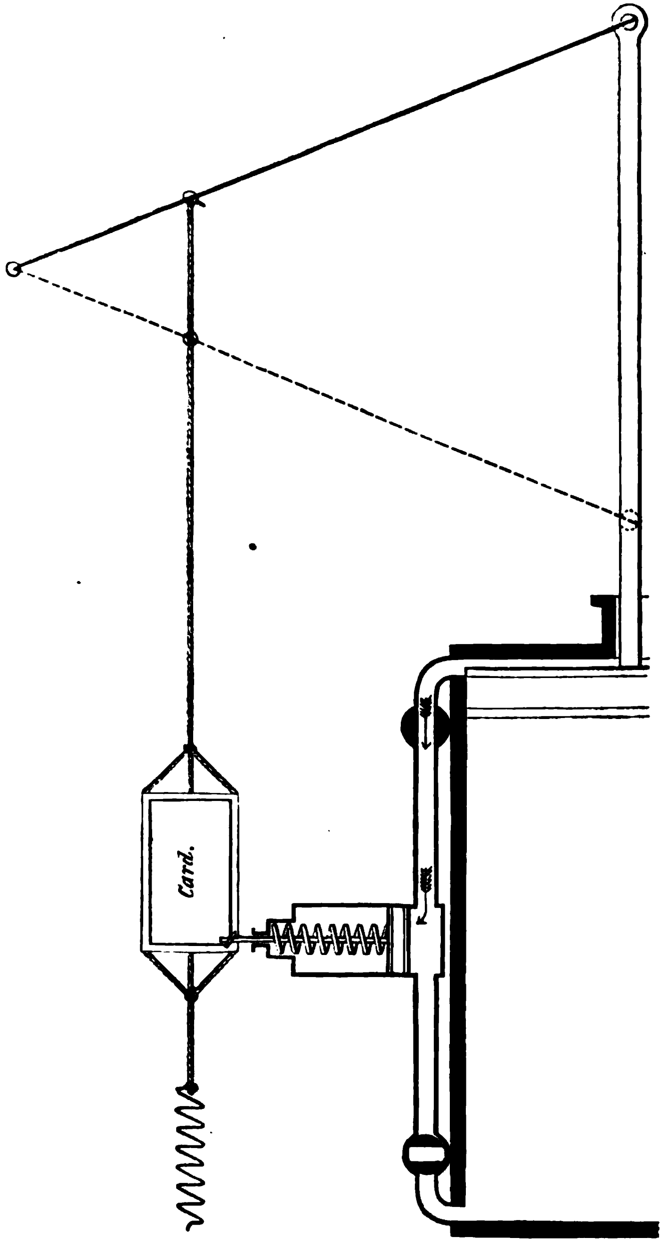


FIG. 28. Watts' indicator.

to which is fixed the centre *o* of the eccentric. I need hardly say to you that an eccentric is simply a crank, with

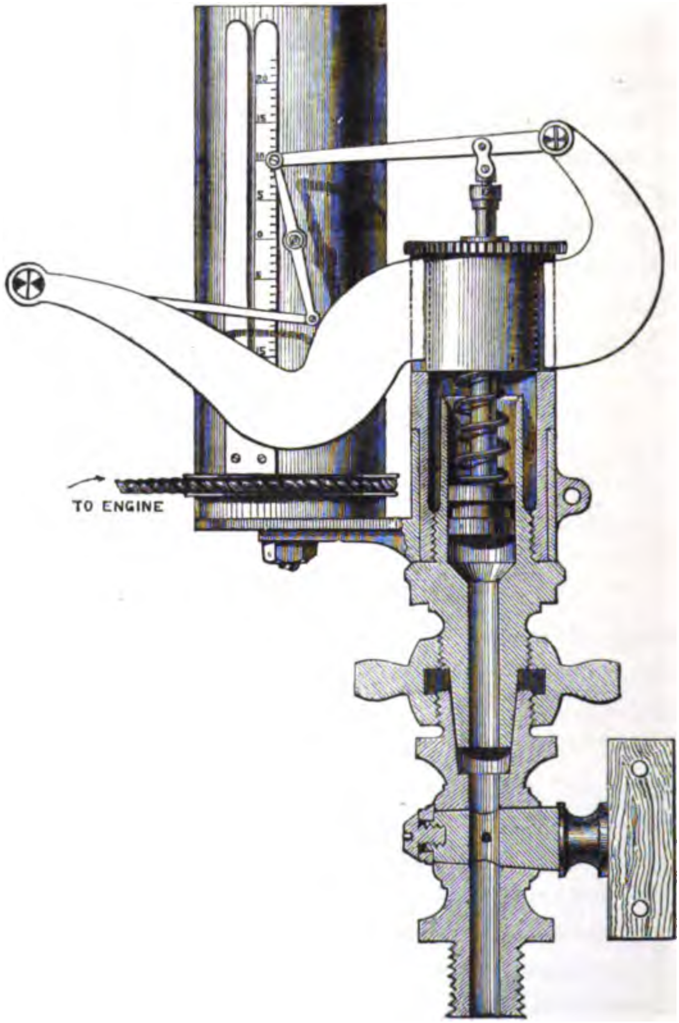


FIG. 29. Richards' indicator.

the pin exaggerated in diameter, until it embraces within it the shaft from which the crank proceeds. This may

appear too obvious to need comment, but I can remember a very protracted litigation, entirely arising upon the question as to whether an eccentric was a crank. Assuming the crank, as shown in fig. 30, to be at one end of its stroke, say the outer end—so that the piston would be at the left-hand end of the cylinder—and that the engine were to revolve in the direction of the arrow—that is to say, so that the top of the fly-wheel should move away from the spectator when standing at the cylinder *—then the centre of the eccentric must be below the shaft, in order that when the shaft revolves (either under the influence of a fly-wheel or under that of a second cylinder at right angles), the eccentric may work the slide valve so as to open the passage *a*, and to give steam upon the left-hand side of the piston, this will at the same time—as the slide valve opens the passage *b* to the exhaust *c*—permit the escape of steam from the right-hand side of the piston. With this arrangement you will see that when, as shown on the second diagram (fig. 31), the crank has travelled through 90 degs., the centre of the eccentric will be at the end of its throw towards the right hand, and the passages *a* and *b* will be fully open to the steam and to the exhaust respectively; and you can also see that when the crank has travelled through the other 90 degs.—so as to finish the half-revolution, or the whole stroke—that the passage *a* and the passage *b* will be both just closed to the steam and to the exhaust respectively. The centre *o* of the eccentric will then be above the shaft, and the crank pin will be at the right-hand end; on the continuance of the motion of the crank pin, the eccentric will work the slide valve so as to introduce the steam to *b* and to allow the exhaust to escape through *a* and *c*. In order to make the

* Although this is the general running direction for ordinary fixed engines, it is the backward direction for a locomotive

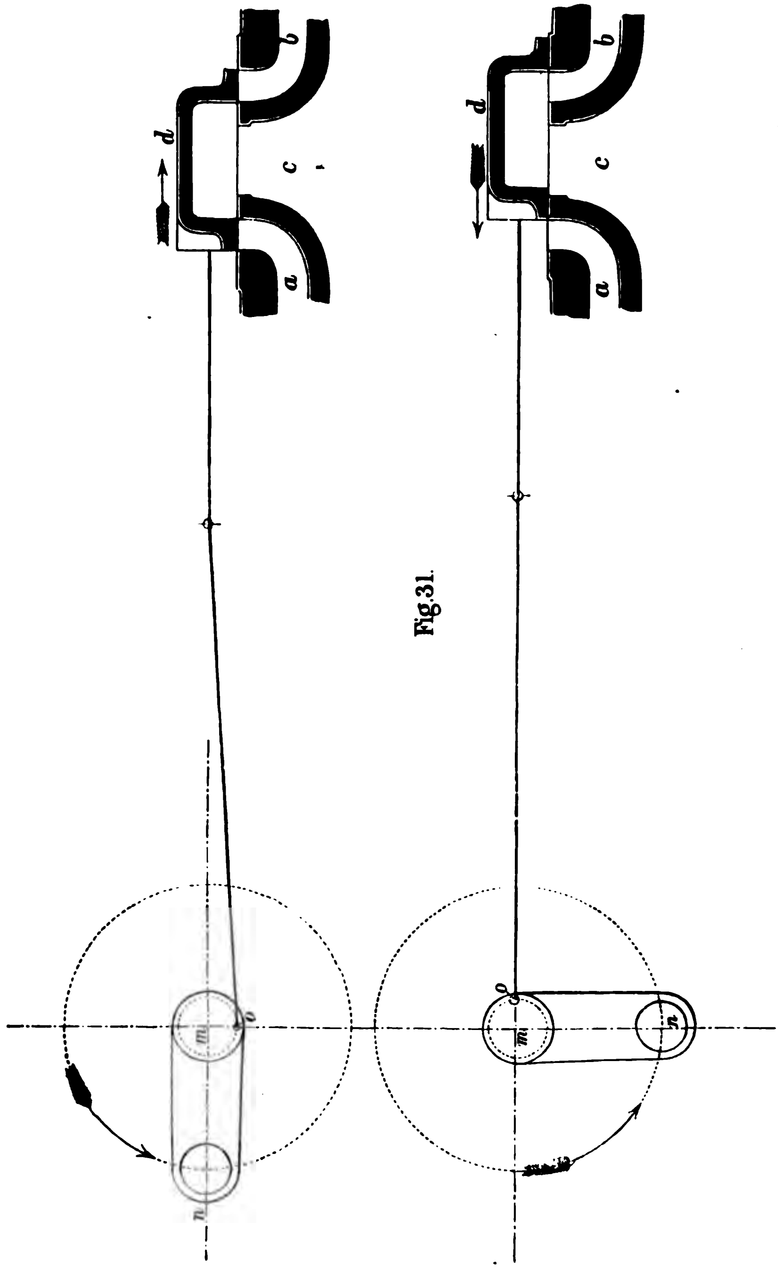


Fig.31.

engine run the other way round, the position of the centre of the eccentric *o* must be changed, so as to be above the crank shaft instead of below it, as it is in diagram 30.

Assuming that the whole pressure of the steam were obtained, immediately the passage opened, and that the whole of the exhaust steam had been got rid of, immediately that the exhaust opened, the result would be to give upon the indicator diagram an absolutely rectangular figure, a 'square card,' such as is shown in fig. 27, but under such circumstances the steam would obviously have no expansion. It may be said that this defect might be cured by a separate valve, either arranged so as to shut off the admission of steam to the steam chest,

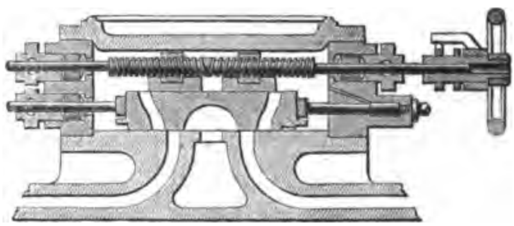


FIG. 32. Ordinary expansion valve on back of slide valve.

or, as shown in fig. 32, situated on the back of the principal slide valve; the form of which is then modified to admit the steam through openings in it, and not over its ends. Such separate valves are not used in locomotives, partly from the difficulty of manipulating them at the time of the reversal, partly from a desire to avoid a multiplication of pieces, and partly from the necessity of keeping down the friction of the slide valves in working, which friction is a source of really appreciable deduction from the power of a locomotive, and a cause of serious wear in all the parts between the crank shaft and the slide valve. It may not perhaps at first sight be clear that the introduction of a valve on the back of another valve will cause this latter

one to be subjected to greater friction in working, because it may be said that it has no more load than that which is due to its own area multiplied by the pressure of the steam; but this is not so, for although it is true that the load on the surface at its under side is not increased, it has in addition the load of the expansion valve on its top side, and the motion of the slide valve is thereby further resisted by the friction due to that load. I do not know whether I need labour this point any further, but I am tempted to do so as I have found it sometimes very difficult of appreciation. Suppose I have two books placed one on the other; the bottom book carried on a table, and that each book weighs 5 lbs., if I pull the two books backwards and forwards I shall have the friction due to a load of 10 lbs. upon the under surface, that in contact with the table, but if I hold the top book still and move the lower one about, then I shall have, in addition to the friction of the 10-lb. load on the under surface, the friction of the 5-lb. load upon the upper surface.

This subject of slide friction is a very serious one in all large marine engines, especially now the pressures in these amount to half those of a locomotive; it is also, as I have said, a very serious one in the locomotive.

Various attempts have been made to cure this defect, and, if time admit, I shall be glad to explain to you a method which has been invented by Mr. Beattie, of the South-Western Railway, a method which appears to give very excellent results (fig. 33).

If a separate valve were used for the purpose of expansion, and we thus got rid of the square card, the arrangement would not cure other defects to which such a disposition of the eccentric and principal slide valve, as that which I have shown, would be liable in quick-running engines. These defects are two: the first, that

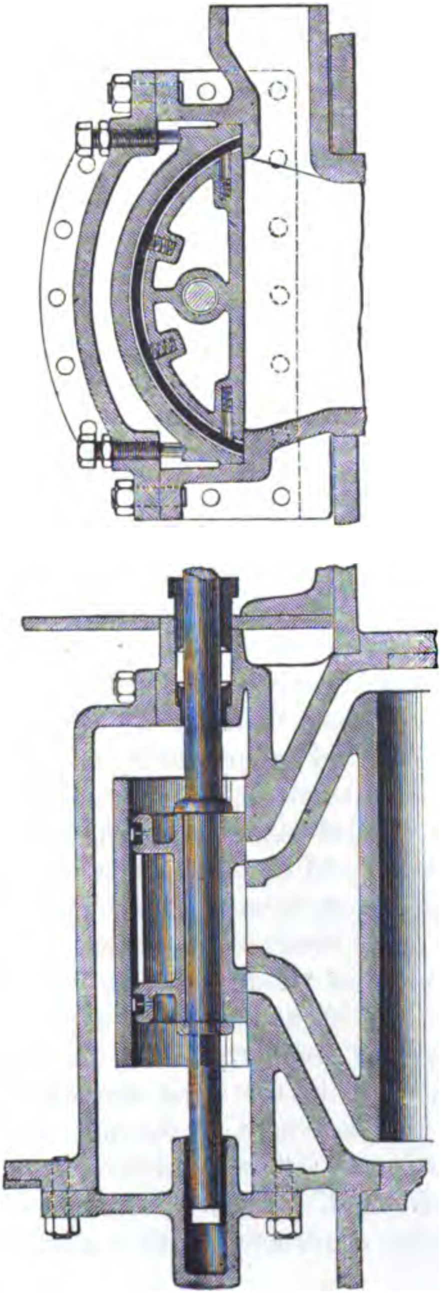


FIG. 33. Beattie's balanced slide valve.

the exhaust steam would not be cleared from the cylinder until some portion of the return stroke was made; and the other, that there would not be any 'cushioning' by the steam, to assist in bringing the reciprocating parts of the engine quietly to rest at the end of each stroke. This latter is a very important point in connection with the smooth working of quick-running engines.

Now, if you will imagine that the slide and eccentric remain as they are in this diagram (fig. 30); but that the angle between the crank and the eccentric is altered, so that (when the crank is, say, at the left-hand end) the eccentric, instead of having its centre *o* in a vertical line below the centre of the crank, should have its centre to the right hand of that line, to the desired extent, the result, as you will see, would be this—that when the crank was on its centre, the steam passage would already be somewhat open, the exhaust passage at the other end would be somewhat open, and the exhaust passage at the left-hand end would have been closed some time before; thus the exhaust steam from the right-hand end of the piston would have had an opportunity of escaping before the termination of the stroke, while the continuance of the exhaust from the left-hand end would be stopped, and the boiler steam would be admitted in opposition to the motion of the piston, thereby 'cushioning' it to rest. This advance of the eccentric in relation to the crank is technically known as 'lead,' and you will see that, by itself, it gives some slight amount of expansion, because it cuts the steam off before the end of the stroke is quite reached. But even in the worst steam engines, valves proportioned as I have here, for the sake of illustration, shown are never used: they are always made with 'lap' as well as with 'lead.' The diagram, figure 34, shows a slide valve thus constructed, with a suitable eccentric

connected to it. The common proportions in use at the present time are here taken. The slide valve is made so that when in its middle position it not only covers the steam passages, but overlaps them by their own width at each end. With these dimensions it is obviously necessary that the travel of the slide (if the passages are to open fully to the steam—which they very commonly do not) must equal four times the width of the passage; and in order that the passage may begin to open just as the crank is on its centre (for that is the condition of things I will first consider), the centre o of the eccentric must be so far in advance of the 'without-lead' position as to have already made one-half its travel, that is, it must be advanced 30 degs. The diagram (fig. 34) shows the ports as before, with the crank at the left-hand end, the centre of the eccentric underneath, but 30 degs. in advance of the centre line, and the slide valve moved to the right-hand, so as just to admit the steam to the port *a*, to press upon the left-hand side of the piston, while the exhaust cavity of the slide valve is already uncovered the full width of the outlet *b*, thereby giving free egress for the exhaust steam before the termination of the stroke. By the time the crank has moved 60 degs., or the piston has made one-fourth of its stroke (always leaving the variations due to the angles of connecting rods and eccentric rods out of consideration, and treating those rods as though they were of infinite length), the centre o of the eccentric will have arrived at its extreme travel to the right hand, as will also the slide valve; at that time the steam port *a* will be fully open as in fig. 35, and the exhaust port *b* will also still be fully open, for the exhaust cavity in the slide valve will have travelled the width of the port beyond it. When the crank has moved a further 60 degs. (equal to three-fourths of the stroke of the

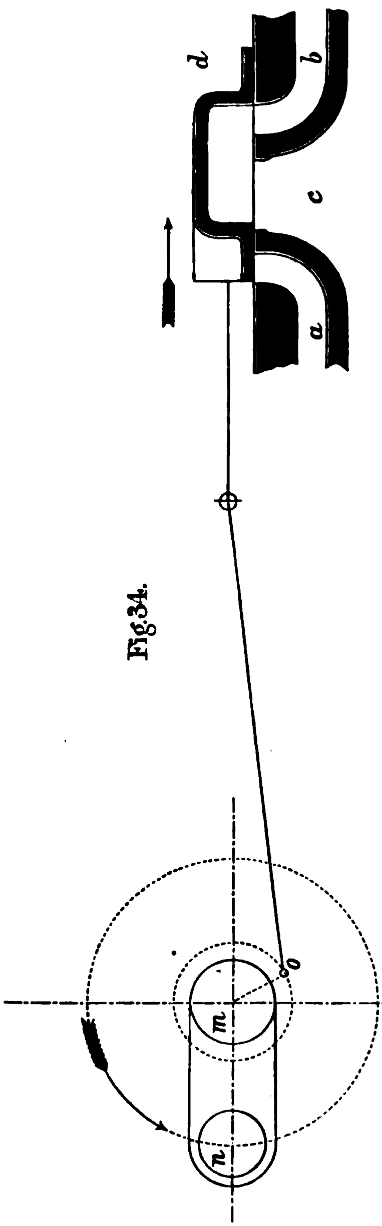


Fig.34.

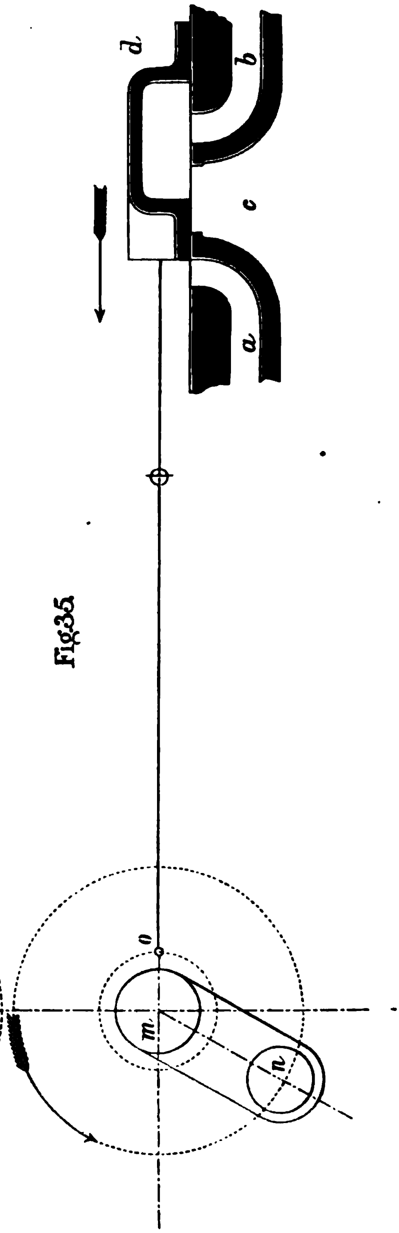


Fig.35.

piston), the centre o of the eccentric will be immediately above its former position in fig. 34, and will have drawn the slide valve back, so as to just close the steam port *a*; from this period the steam will commence expanding in the cylinder. The exhaust *b*, however, will at this point still be wide open, but will gradually close as the eccentric continues its travel, and will be entirely closed when a further 30 degs. of motion has been made, for this will bring the centre o in a vertical line immediately above the crank shaft, and will therefore put the slide valve in its middle position. From this point there will be exercised compression of the steam contained in the cylinder on the

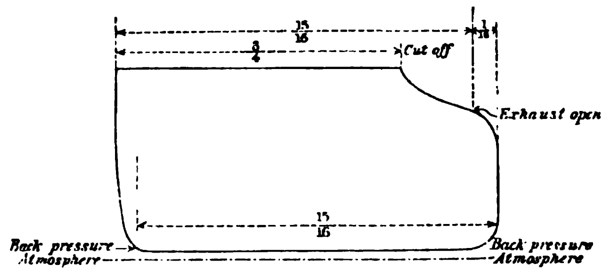


FIG. 36. Imaginary indicator diagram cutting off at three-fourths.

right-hand side of the piston. At this time also the exhaust will commence from the port *a*, at the left-hand end of the cylinder; but the crank will now have made a total movement of 150 degs., and the piston will, therefore, have traversed about 15-16ths of its stroke. With such an arrangement the indicator will no longer afford a square card, but a card of the form shown on the diagram figure 36. I will now ask you to imagine that this form of construction may be still further improved by giving the slide valve some 'lead,' so that the steam passage may be opened preparatory to the arrival of the piston at the end of its stroke; the results of this will be to cut off the

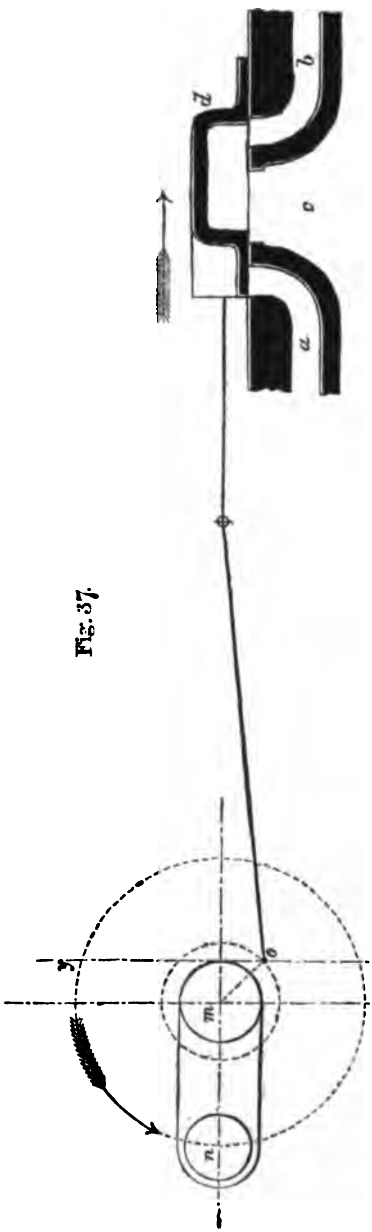


Fig. 37.

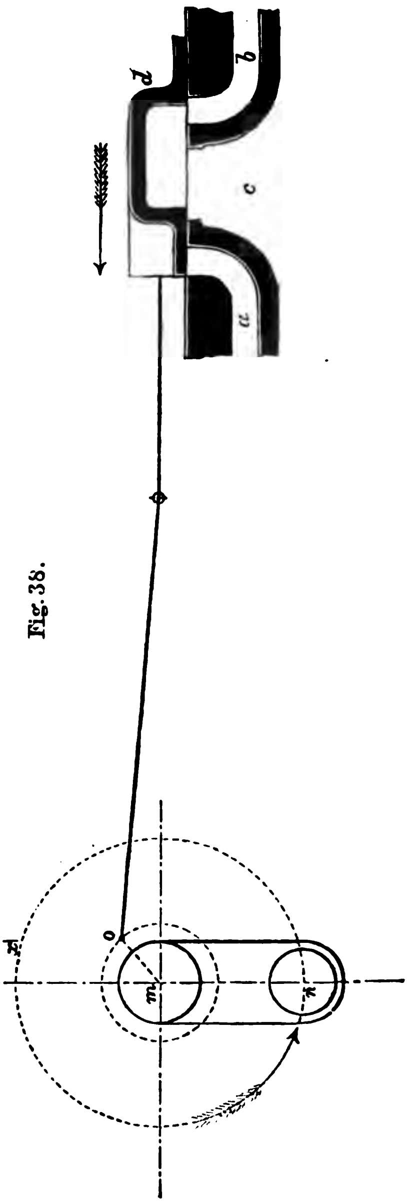


Fig. 38.

steam considerably earlier, to let the exhaust go a little earlier, and also to give a little more compression.

We will next consider how, retaining these proportions of slide valve and ports, it would be possible by changes in the dimensions, and in the lead of the eccentric, to cause the cut off to take place more quickly. I will again imagine that the steam port *a* begins to be uncovered exactly when the crank is at the left-hand end of its stroke, but that the slide valve is to be driven by an eccentric of so small a throw that it will no longer cause the slide valve to travel far enough to the right, to open the steam passage the whole way, and that we are about to content ourselves with opening it only ·414 of its width. These conditions could be satisfied by a radius of throw of the eccentric, which, if the width of the passage be called unity, should be the root of 2 (1·414); and to enable such an eccentric to put the slide valve into the position of being just ready to open when the crank was on its centre, the centre *o* of that eccentric must have a lead of 45 degs., as is shown in fig. 37. With this arrangement, by the time that the crank has travelled 45 degs.—that is, by the time that the piston has made 3-20ths, in round numbers, of its whole stroke—the slide valve will have made its extreme travel to the right, or will have opened the port *a* ·414 of its width, and by the time that the crank has travelled a further 45 degs., or, in other words, by the time that the piston has made half its stroke, the centre *o* of the eccentric will be immediately over the point from which it started, and therefore will have closed the slide valve (see fig. 38), cutting off the steam at half-stroke. A further 45 degs. of the crank will bring the slide valve to the centre, at which position the compression on the right-hand side of the piston, and the exhaust from the left-hand side of the

piston will commence, and at this time the piston would have travelled about 17-20ths of its stroke. The diagram resulting from this arrangement is shown by fig. 39.

You will see that whatever may be the angular 'lead' and the 'throw' of the eccentric, the position of its centre, at the time when the crank is at the left-hand end of its stroke, must be somewhere on the line $x\ y$, as that line is so much to the right hand of the central position of the throw or travel of the eccentric as is equal to the lap of the slide valve—the lap in this case being assumed to be the width of one passage—and that this amount of travel from the central position must be made before the

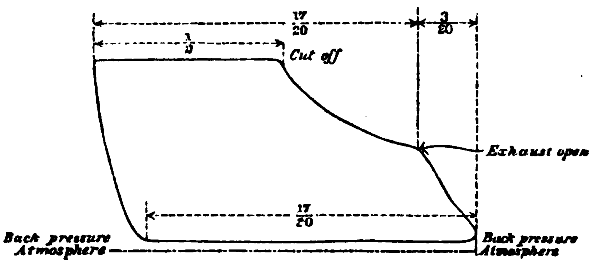


FIG. 39. Imaginary indicator diagram cutting off one-half.

slide valve can be just in the act of opening. Therefore, it is clear that if some means were provided by which the centre of the eccentric could be shifted at will, along the line $x\ y$, from x to any point up to the centre line, the proportion of the stroke during which steam is admitted could be lessened at will, until by the time the centre o had reached the horizontal line, the admission of steam would cease, as there would be no opening of the slide whatever.

You will remember I called your attention to the obvious fact, that if the centre of the eccentric were placed above the shaft instead of below it, while the crank was assumed to be at the left hand, the engines

would go in the reverse direction. If, therefore, the movement of the centre could be continued along the line *x y* above the centre line towards *y*, then we should obtain the reversal of the direction of motion of the engine; and, according to the position that the pin occupied in the line *x y* above the horizontal line, so would be the rate of expansion in the backward direction, corresponding to the rates of expansion in the forward direction when the centre was at a similar position but was below the line.

Having thus prepared the way, I now come to the 'link motion'—a contrivance by which it is possible, while the engine is running, to produce on a slide valve precisely the same effects as could be obtained by the shifting of the centre that I have indicated.

I have thought it would make this subject more clear if I were to produce before you a large elementary model of the link motion, and in order that I should not be encumbered, in that model, with considerations arising from the curvature of the link, I have made the cylinder (the slide valve of which this model is to work) capable of being moved up and down in reference to the link, rather than make the link capable of being moved in reference to the cylinder, for this latter movement would have involved the curvature of the link. I need hardly say this is not the construction in practice. See figs. A to H in fig. 39A.

With a link motion, two eccentrics are employed—one having its centre suitably placed for the least expansion when in forward gear, the other having its centre suitably placed for the least expansion in back gear, and I will adhere for this purpose of least expansion to the proportions given by the 30 degs. of advance of the centre of the eccentric, that is to say, each eccentric could cut

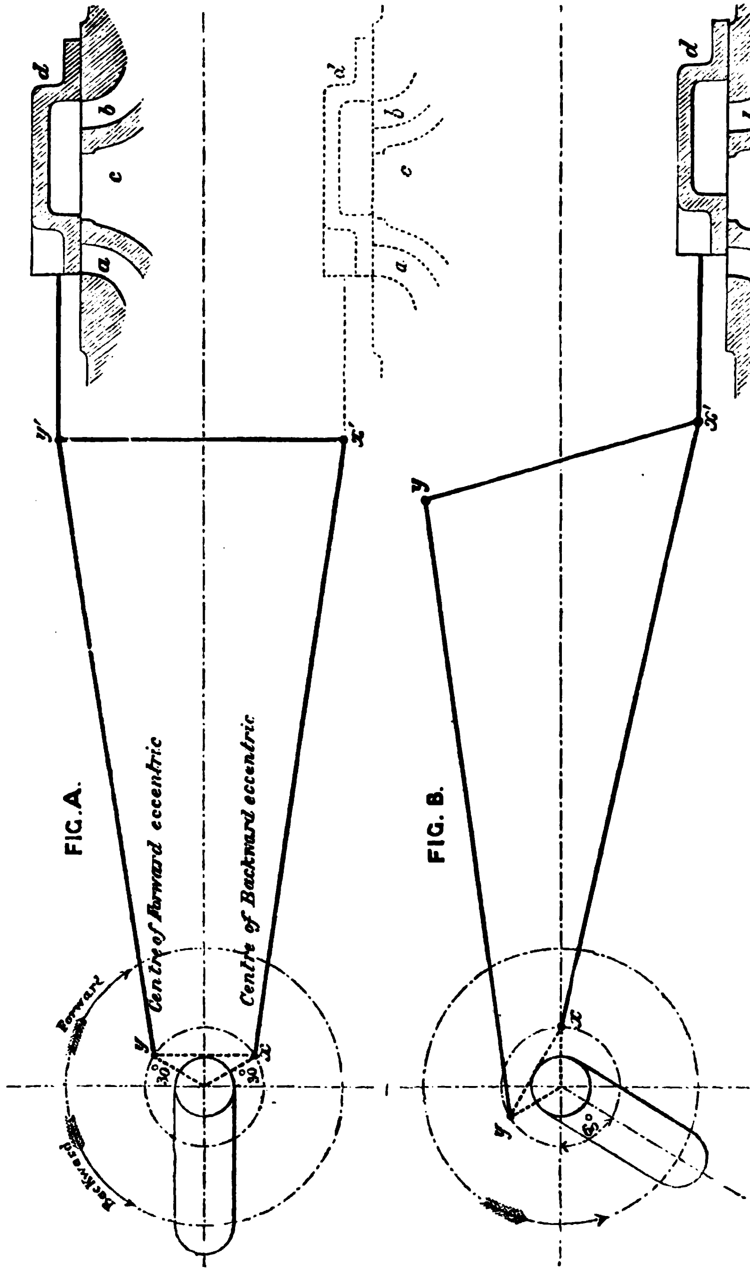


FIG. 39A (pp. 81–84).

NOTE.—In all the figs. of diagrams (figs. G to H) the eccentric rods are assumed to be of indefinite length.

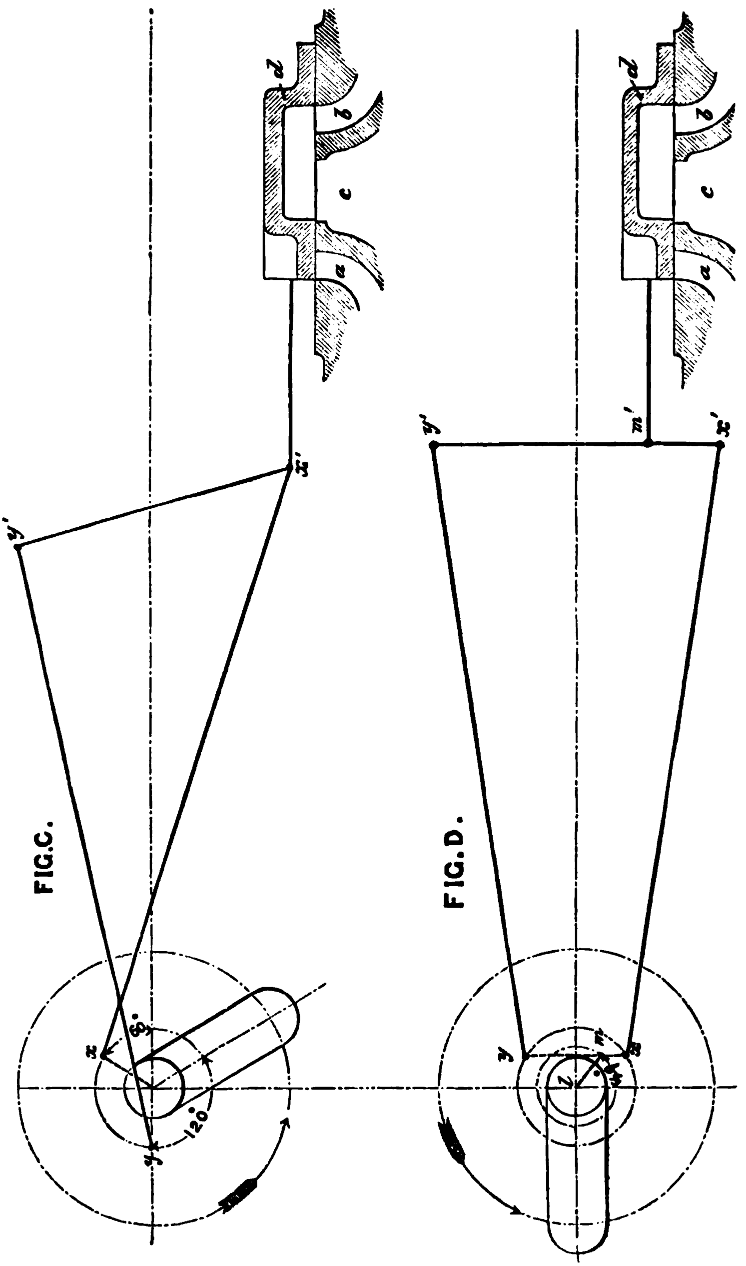


FIG. C.

FIG. D.

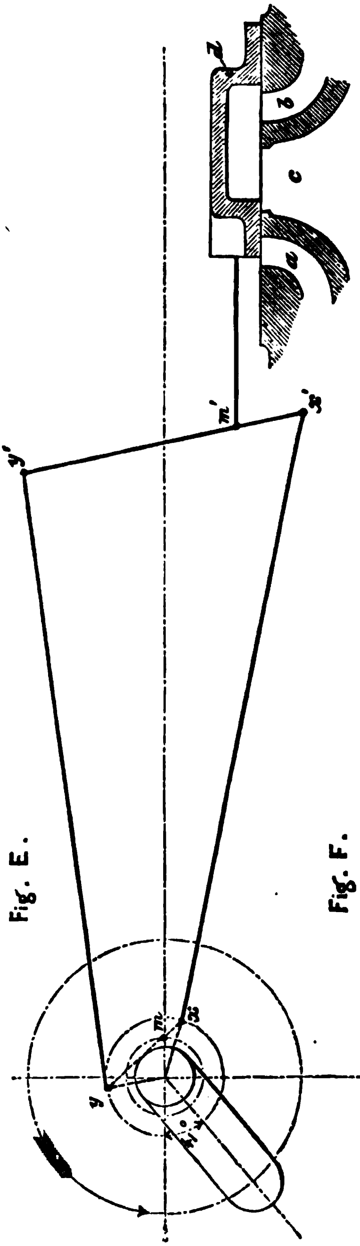


Fig. E.

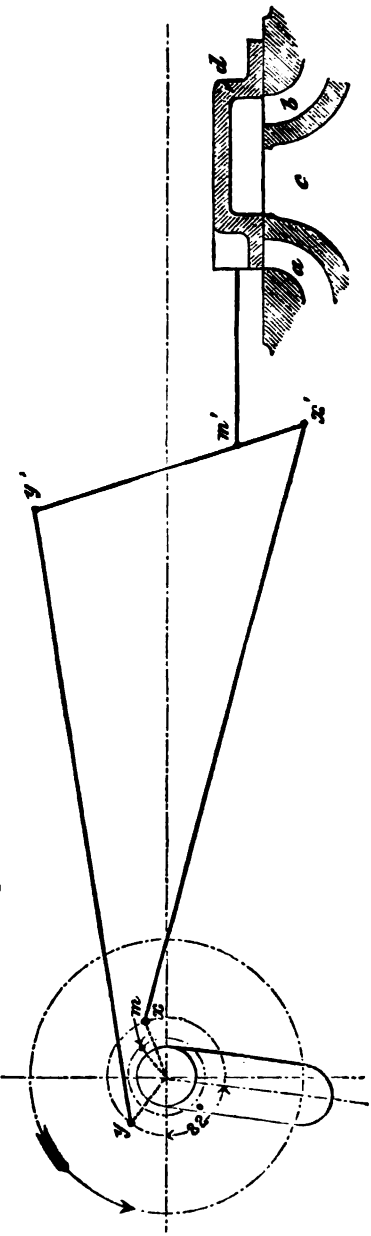


Fig. F.

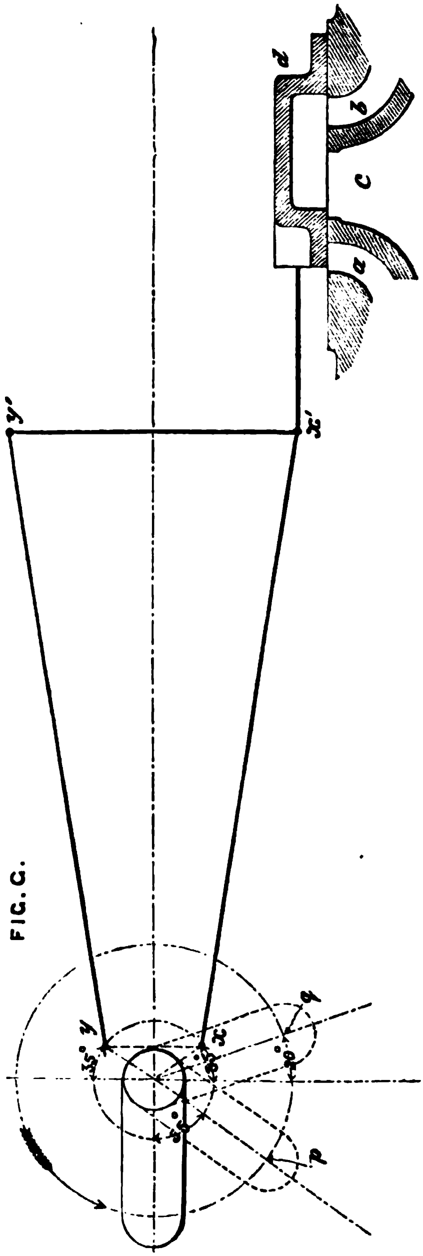


FIG. G.

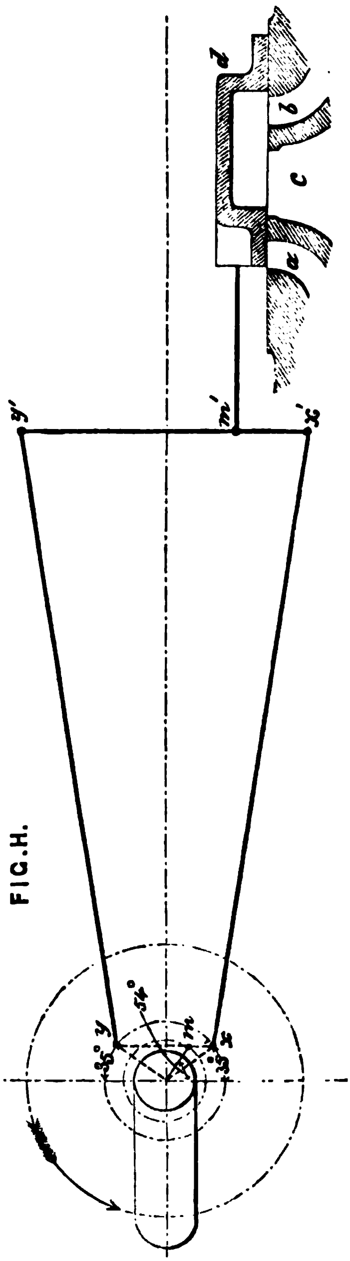


FIG. H.

off the steam at three-fourths of the stroke of the piston. Now, if the eccentric rod of one of these eccentrics be attached to the top end of a long bar $x' y'$, and the rod of the other eccentric be attached to the bottom end of that bar, the top and bottom ends of that bar will have the same relative position to the right and to the left as the centres of the two eccentrics have, that is, as the line $x y$, uniting those points, has (although the bar may not be parallel to the line $x y$, because it is much longer than that line). If, therefore, the slide rod be attached to any point in this bar, the rod will have precisely the same motion as if it were driven by a crank pin placed in the same relative position in the line $x y$ that the point of attachment is placed in, in the bar $x' y'$. For example, if it be placed at the top end of the bar, it will have the exact motion which would be given by the eccentric which is in connection with the top end; if at the bottom end of the bar, then it would have the exact motion which would be given by the eccentric in connection with that end; if at the middle of the bar, then it would have the motion that would be given to the centre of the line $x y$, which, you will remember under the circumstances stated, is one which would just, not open the steam passage at all.

We will now put the model into operation, and show that when the crank is, say, at its left hand (see diagram 39A, fig. A), the link will be vertical, and therefore the moving of the slide stalk up and down this link will have no effect whatever in changing the position of the slide valve. Similarly, when the crank is turned half round so as to bring the crank to the right-hand end, the link will again be vertical, and again there will be no effect by altering the point where the slide stalk engages with the link. But let us next put the crank to an angle of 60 degs.

in the backward direction (fig. B). The backward eccentric x is now at its full throw, and if the slide stalk be connected with the lower end of the link x', the left-hand steam passage will be open to its fullest extent.

If we now cause the crank to travel a further 60 degrees (see fig. C), or a total of 120, equal to three-fourths of the stroke of the piston, it will be found that the backward eccentric is immediately above the position which it occupied at the commencement of the stroke, and that thus the slide valve has closed the port, and expansion has commenced. Restoring the crank to zero, let the slide stalk be raised until it is connected to the link at a point m', say midway between its lower end, x', and its centre (see fig. D), a point which, when set out upon the line $x\ y$, and connected by a radial line to the centre of the crank shaft, would be found (see $l\ m$ in fig. D) to give the equivalent of an eccentric having a lead of about 49 degrees instead of the 30, and a throw of rather less than two-thirds of that of the actual eccentrics; at this point of attachment to the link the extreme motion of the slide-valve, which will be only sufficient to open the steam passage about one-third, will be found to occur when the crank has travelled the difference between the 49 degrees of lead and 90 degrees, that is to say, when the crank has travelled 41 degrees (see fig. E), equivalent to approximately $\frac{1}{8}$th of the stroke of the piston; and when the crank has made a further 41 degrees, or 82 in all (see fig. F), equal to about 43 per cent. of the stroke of the piston, the imaginary centre of the diminished and advanced eccentric we are considering, will be immediately above the position in which it was when the crank was at the commencement of its stroke (see fig. D), and the slide valve will be reclosed, and expansion will begin.

I need not occupy further time by tracing the effects of shifting the point of attachment to other parts of the length of the link below its centre, as it will suffice to say that the period of cutting off the steam may be hastened until it be made infinitely short; calling attention, however, to the fact that this hastening is accompanied by a continual diminution of the width of the opening to admit the steam to the cylinder. Similarly I need not occupy your time by showing on the model that if the point of attachment be anywhere above the centre of the link, the engine will revolve in the reverse, or forward direction, and that the expansion will follow the same rules as it obeyed when the engine was assumed to be running in back gear.

We have now considered the action of the model on the assumption that the ports are made to open to the steam exactly as the crank is on the centre, but in practice the ports are always open to the steam before the crank is on a centre—as already mentioned when speaking of the single eccentric—that is to say, the line $x\ y$ is put still further from the centre of the crank. I believe I can change the model and can show its effect in working.

For this purpose I will give a further lead of 5 degrees to each eccentric, making a total of 35 degrees (see fig. G): this will have the effect of moving the line $x\ y$ and with it the slide, so as to open the passage to the steam rather more than one-seventh of its width when the crank is on its centre: if now the attachment of the slide stalk to the link be made at its lower end, the extreme opening of the steam passage will of course be effected when the crank has travelled only 55 degrees, as p (instead of the 60 degrees), that is to say, when the

piston has made about 21 per cent. of its stroke, and the expansion will commence when the crank has made a total travel of 110 degrees, as *q*, or 67 per cent. of the stroke of the piston, instead of the 75 per cent. required when the slide had no lead; moreover the steam will be admitted on the opposite side of the piston, to 'cushion' it when the crank has made 175 degrees, or when the piston has only got ·2 of one per cent. of its stroke to perform.

Next let us reattach the slide stalk at the midway position between the lower end of the link and its centre; now if we once more lay this on the diagram (see fig. H), we shall find we have the equivalent of an eccentric having a radius of about seven-tenths of that of the actual eccentric, and a lead of 54 degrees (see *m*). With this arrangement the passage will open to the steam only four-tenths of its width, and will do so when the crank has made 36 degrees, and the piston has travelled about 9 per cent. of its course, while the slide will close the steam port when the crank has made a total motion of 72 degrees, and the piston has travelled a little over one-third; and under these circumstances the steam will be admitted to the other side of the piston to 'cushion' it when the crank has made about 171 degrees, and the piston has ·7 of one per cent. of its stroke remaining to be performed.

We now come to the way in which the links are made in practice. One mode, and probably the most common one (fig. 40), is to make the link with a curvature towards the crank shaft, and to allow it to move upon the slide block, so that when the crank is on its centre, the movement of this curved link past the block shall not materially vary the position of the slide, the variations in expansion and in direction of motion of the engine, back-

wards or forwards, being obtained by raising or lowering the curved link in relation to the block.

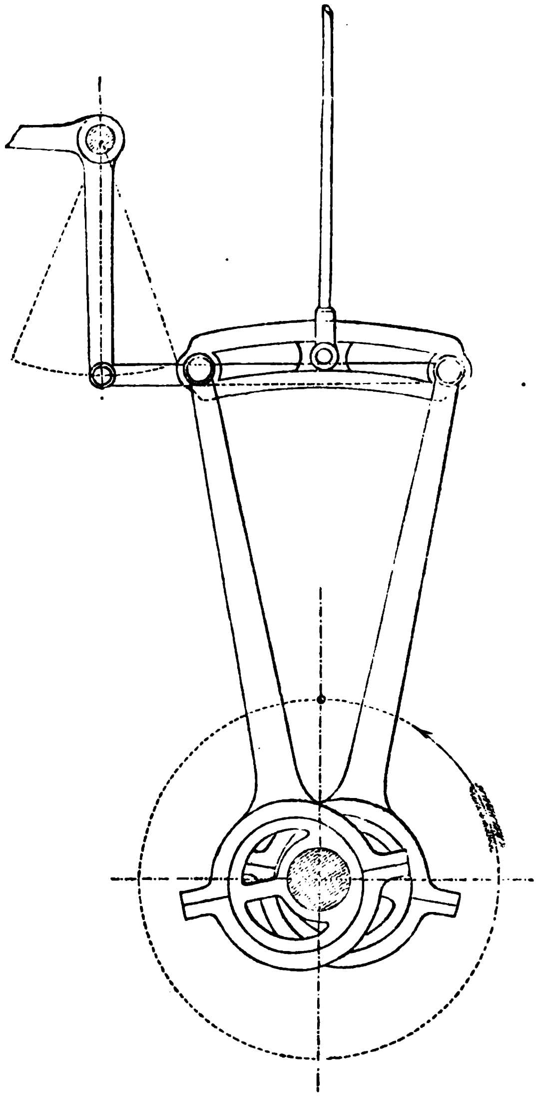


FIG. 40. Ordinary link.

The next mode (fig. 41) is one wherein the link is not

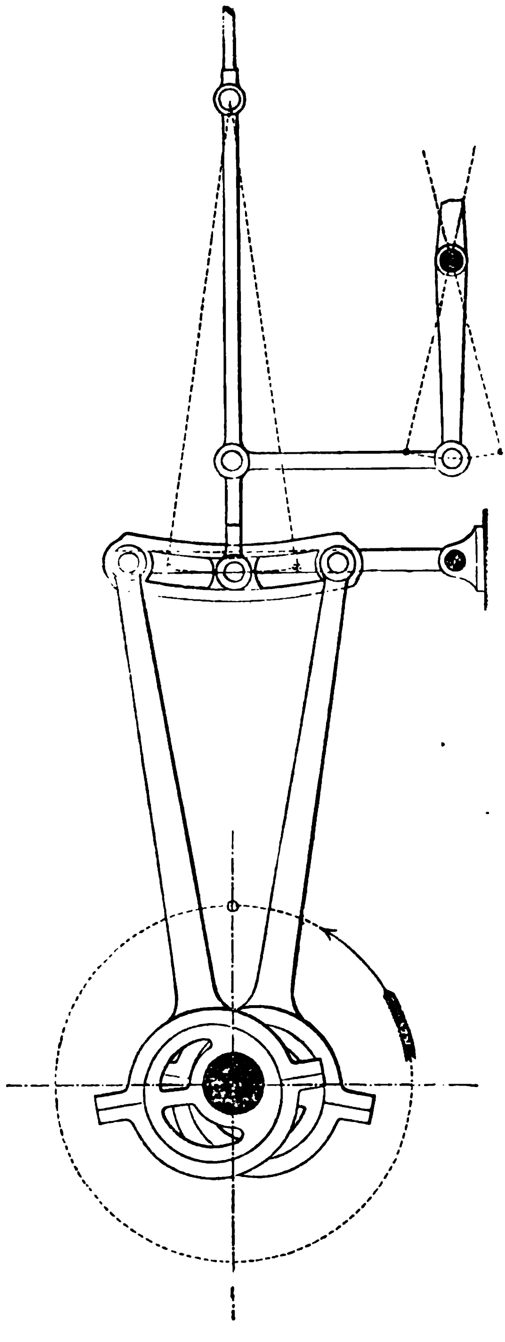


Fig. 41. Reverse radial link.

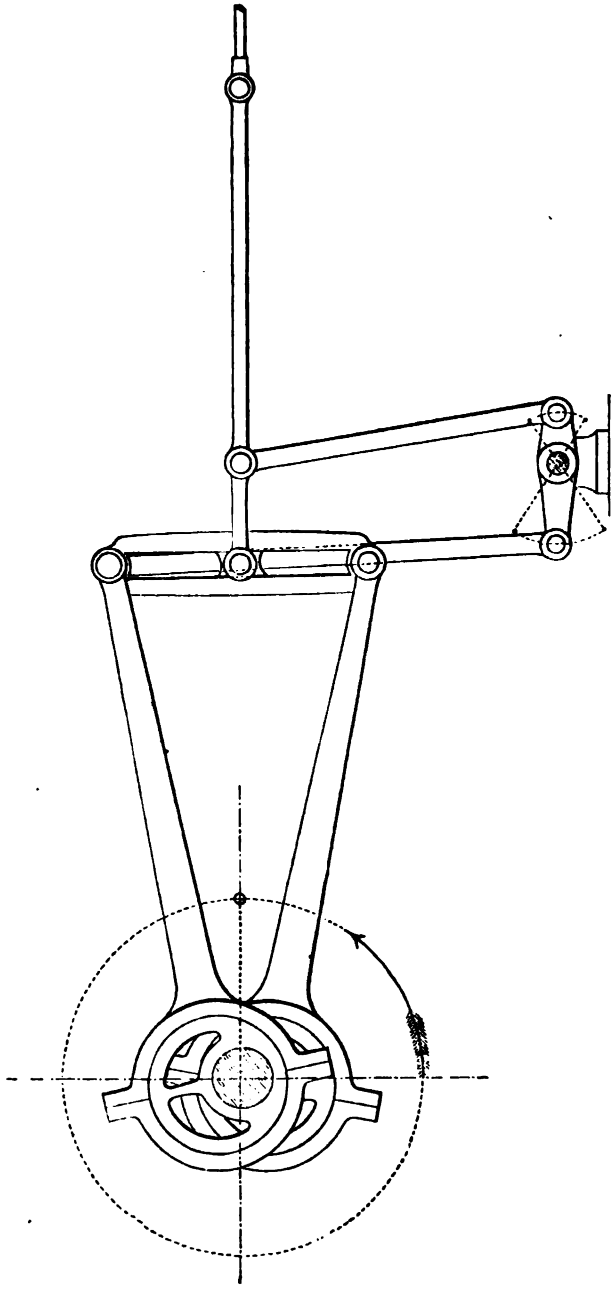


FIG. 42. Straight link.

raised or lowered, but is suspended by a sling, and where the slide stalk is provided with a jointed rod, the back end of which can be caused to rise or fall within the link; in this case the curvature of the link is in the direction, opposed to that which is required when the link itself is movable, that is, the convexity and not the concavity of the curve is towards the crank-shaft.

The third mode is that known as the straight link (fig. 42). In this construction both the link and the rod rise and fall, the result being that the motion of each is halved, and that the link is made without curvature.

Whichever construction is employed, and whether it be the link, or the jointed end of the slide stalk, that is raised and lowered, or as in the case of the straight link, both link and stalk be raised and lowered, the movements are made by the engine driver operating by the reversing handle. Formerly these handles were provided with a species of trigger and a spring catch, which enabled the driver to engage them with any one of a number of notches made in a fixed segmental piece, alongside the lever: the central notch was that for mid-gear, while the end notches in either direction were those for full gear forward or full gear backward, the intermediate notches being those for the various grades of expansion. A driver who is careful of his fuel regulates the pace of his train, not as was formerly done by the greater or less opening of the 'regulator' (that is the valve which shuts off, or admits the steam from the boiler to the cylinders), but, leaving this full open, he varies the power developed in the engine, by giving more or less expansion, and thus, when he has a light load, or when going down a gentle incline, or when any other circumstance enables him to get along without demanding the utmost work from his engine, he profits by it to use the steam more and more

expansively. There is a difficulty, however, in moving the links while the steam is on by means of these hand-levers, for, owing to the angle made by the link at various parts of its stroke, there is a strong pull at times upon the lever, and some danger of the lever overpowering the driver, when he takes the catch out of contact with the notch. This danger has led to the abandonment of the lever, and to the substitution of a screw. For a long while the change was resisted on the ground that the screw was not quick enough, and that therefore a driver had not a sufficiently speedy control of his engine when danger was to be apprehended, and contrivances were resorted to, such as split nuts, which could be opened to admit of the quick pull of the lever; but this was a refinement that was not found necessary, and now a large number of new engines are fitted with screws to work the link motion, the lever and catch being entirely abandoned. This screw has the further advantage of giving the driver complete control over the link, notwithstanding the pressure of steam may be on the slide-valve, and it also enables him to adjust the period of cut-off, with the greatest possible nicety.

I will bring this second lecture to a conclusion by saying that Mr. W. Kirtley, the Locomotive Superintendent of the London Chatham and Dover Railway, has kindly offered us the use of one of his new Locomotives in steam, for inspection, on the morning of the day for our next lecture, and has been good enough to further offer to fix my Indicator to it, so that we may take diagrams on our run down with the train from town, and so also that we may take diagrams in your presence from the 'empty engine,' when it is placed on the Admiralty Branch line, the use of which, I am glad to find. we can have for the requisite time.

LECTURE III.

REVERSAL—INDICATOR DIAGRAMS—WALSCHAERT GEAR—DISTRIBUTION OF WEIGHT—CURVES—BOGEYS—'CONTRE VAPEUR' BRAKE.

THIS morning we have had the fulfilment of Mr. Kirtley's promise, which I announced to you at the close of our last lecture, and you have had the opportunity of examining the various parts of the engine to which I directed attention; fig. 43 is a sketch of the engine and tender with some of the leading dimensions annexed. This morning you had also the opportunity of seeing diagrams taken from this engine, running 'empty.' I propose to call your attention to enlargements of some of the diagrams taken when travelling from London to-day with a train behind the engine, and I will employ that occasion to explain a paradox in 'Locomotive' working under certain circumstances. The paradox is this —that when the connection between the link and slide is made at the centre of the link, or when in Locomotive phraseology the link is in mid-gear or in 'middle notch,' as it used to be called, the Locomotive will continue to work in whichever direction it might have been running before the link was put into mid-gear, that is to say, if it had been going forward it would continue to travel forward; if it had been going backward it would continue to travel backward, and it would even be competent to exert a considerable amount of useful work under these circumstances.

I have more than once during these lectures called your attention to the fact that the link is the implement

LONDON CHATHAM AND DOVER RAILWAY. Wm. Kirtley, M. Inst. C.E., Locomotive Engineer.

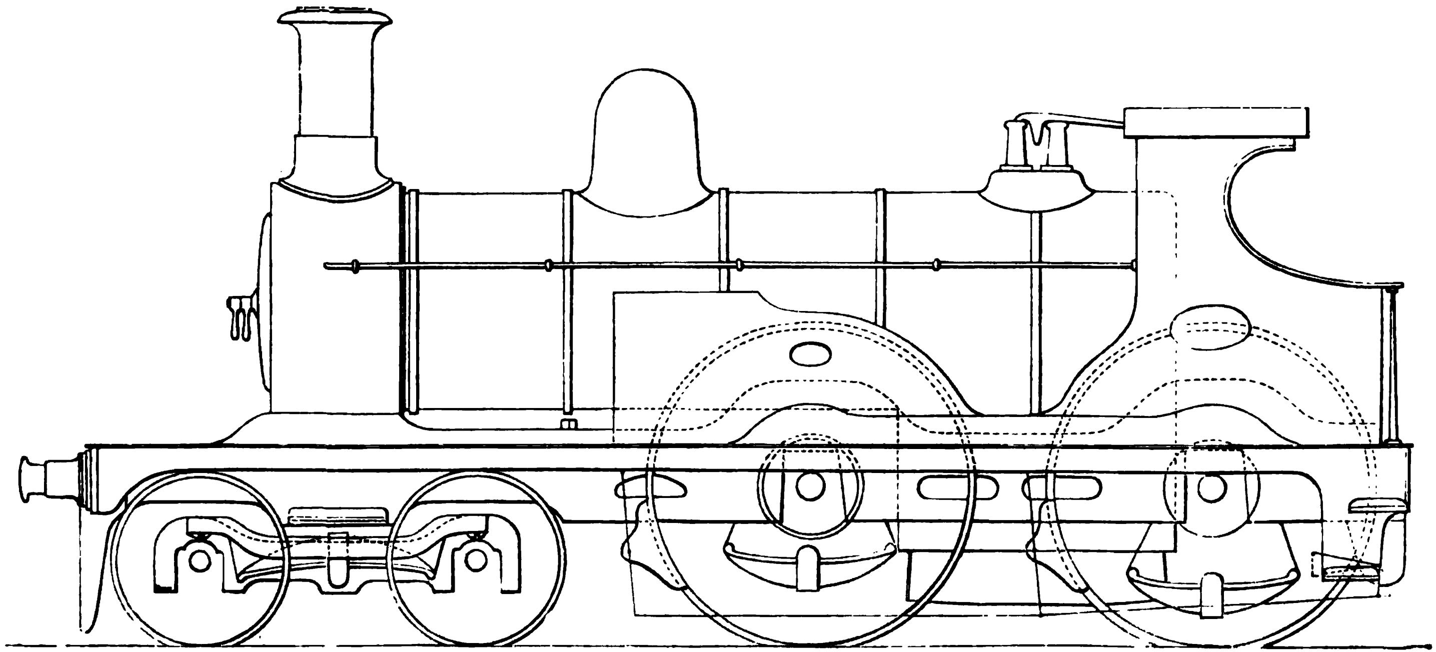


Fig. 43. Inside cylinder express passenger bogey engine. No. 159, December 1877.

LEADING DIMENSIONS

Total weight empty	38 tons.
Total weight in running order on pair of trailing wheels	13 tons.
Do. pair of driving wheels	13 tons 10 cwt.
Do. 4 wheels of bogie	15 tons 10 cwt.
Total weight in running order	42 tons.
Diameter of cylinders (inside cylinders)	$17\frac{1}{2}$ ins.
Length of stroke	2 ft. 2 ins.
Depth of steam and exhaust ports	1 ft. 2 ins.
Width of steam port	$1\frac{1}{4}$ ins.
Width of exhaust port	$3\frac{1}{2}$ ins.
Length from outside to outside of steam ports	$8\frac{1}{2}$ ins.
Length of the slide	$10\frac{5}{8}$ ins.
Lap at each end	1 in.
Greatest amount of steam ports open when link is in full gear	$1\frac{1}{16}$ ins.
The lead of the slide forward gear . . . $\frac{3}{16}$ front end	$\frac{3}{32}$ back end.
Do. do. backward gear . . . $\frac{1}{16}$ front end	$\frac{3}{32}$ back end.
(being the amount of the total lead of the eccentrics minus the lap)	
Travel of the slide	$4\frac{1}{16}$ ins.
Maximum area of blast nozzle	=7 ins. diam.
Minimum area of blast nozzle	=5 ins. diam.
NOTE.—The blast pipe is fitted with means of varying the size of the aperture.	
Diameter of piston rods	$2\frac{3}{4}$ ins.
Diameter of slide stalks	$1\frac{5}{8}$ ins.
Length of piston rod guide blocks	1 ft. 2 ins.
Width of do.	8 ins.
Total guiding surface of the two blocks to each piston	168 sq. ins.
Length, centre to centre of connecting rods	5 ft. 10 ins.
Sectional area of smallest part of connecting rod	6·5625 sq. ins.
Length of eccentric rods	4 ft. 3 ins.
Throw of the eccentrics	$6\frac{1}{2}$ ins.
Total length of link from centre to centre of eccentric rod pins	$16\frac{1}{2}$ ins.
Diameter of trailing and driving wheels	6 ft. 6 ins.
Diameter of bogie wheels	3 ft. 6 ins.
Diameter of axle of trailing and driving wheels in the journals	$7\frac{1}{2}$ ins.
Length of journals in do.	$7\frac{3}{4}$ ins.
Diameter of do. in the body part	7 ins.
Diameter of bogie axle in the journals	6 ins.
Length of journals in do.	9 ins.
Diameter of do. in the body part	$5\frac{3}{4}$ ins.
From back end of frame to centre of trailing wheels	4 ft.
From centre of trailing wheels to centre of driving wheels	8 ft. 4 ins.

From centre of driving wheels to centre of bogie		9 ft. 10 ins.
From centre of bogie to front end of frame		5 ft.
Total length of frame		27 ft. 2 ins.
Centre to centre of bogie wheels		5 ft. 9 ins.
Total length over buffers of engine and tender		50 ft. $3\frac{3}{4}$ ins.
From top of rail to centre line of buffers		3 ft. 5 ins.
From top of rail to top of chimney		13 ft. 4 ins.
From top of rail to top of footplate		4 ft. $1\frac{1}{2}$ ins.
From top of rail to centre of boiler		7 ft. 2 ins.
Diameter of barrel of boiler (inside)		4 ft. $2\frac{1}{8}$ ins.
Length of do.		10 ft. 2 ins.
Number of tubes		200
Outside diameter of tubes		$1\frac{3}{4}$ ins.
Length of firebox (outside)		5 ft. 9 ins.
Thickness of barrel plates		$\frac{7}{16}$ in.
Longitudinal seams are double rivetted with butt strips inside and out		
Circumferential seams are single rivetted with an external butt strip		
Thickness of external plates of firebox		$\frac{1}{2}$ in.
Thickness of internal plates of firebox (copper)		$\frac{1}{2}$ in.
Thickness of firebox tube plate (copper)		$\frac{15}{16}$ in.
Thickness of smokebox tube plate (iron)		$\frac{7}{8}$ in.
Diameter of screw stays		$\frac{7}{8}$ in.
Distance apart centre to centre of do.		4 ins.
Width of tyres		$5\frac{1}{2}$ ins.
Thickness of tyres on the tread		3 ins.
Length, centre to centre of spring links for trailing and driving wheels		3 ft. 4 ins.
Do. spring links for bogie wheels		4 ft.
Width of springs for trailing and driving wheels		$4\frac{1}{2}$ ins.
Do. do. bogie wheels		5 ins.
Total depth of springs for trailing and driving wheels		$6\frac{1}{2}$ ins.
Do. do. bogie wheels		7 ins.
Thickness of spring plates (throughout)		$\frac{1}{2}$ in.
No. of plates of springs for trailing and driving wheels		13
Do. bogie wheels		14
Heating surface—		
200 tubes $1\frac{3}{4}$ ins. external diameter	962 sq. ft.	
Firebox	107 ,,	
Total heating surface		1,069 sq. ft.
Grate area		16·3
Working pressure, 140 lbs. per square inch.		

for varying the amount of expansion, and is thereby the means of altering from time to time the power developed by the engine; it is also the implement by which the direction of motion of the engine is reversed. While bearing these two functions in mind, it may be interesting to revert for a few minutes to the historical part of our subject, and to describe to you what modes were adopted in locomotive practice to fulfil these ends, before the link was in use.

One of the earliest systems of reversal was that which is to be found in the model of the 'Rocket' before you, where each engine has only one eccentric. That eccentric is loose upon the shaft, and is driven by the engine (in the forward direction if the engine be going forward, or in the backward direction if the engine be going backward) by means of a stop upon the shaft, which engages with either the one or the other of two stops upon the eccentric, see fig. 44. With this arrangement handles had to be provided by which the driver could lift the two eccentric rods (one for each engine) off the pins that attached them to the way-shaft levers: having lifted them clear, he, by other handles, moved the slides by hand, and in that way admitted the steam to the one side or the other of the piston and caused the crank shaft to make a partial revolution, the eccentric standing still until it was over, taken by the stop upon the shaft, which drove it onwards, and the driver then threw the eccentric rods again into gear. Such an arrangement as this admitted of a certain amount of expansion, because the stops could be so set upon the shaft as to give lead both in forward and in backward gear, but the slides had, as I have said, to be worked at the time of reversal by hand.

Another arrangement which also admitted of a certain amount of expansion, but also involved the working the slides by hand, was to have two eccentrics for each

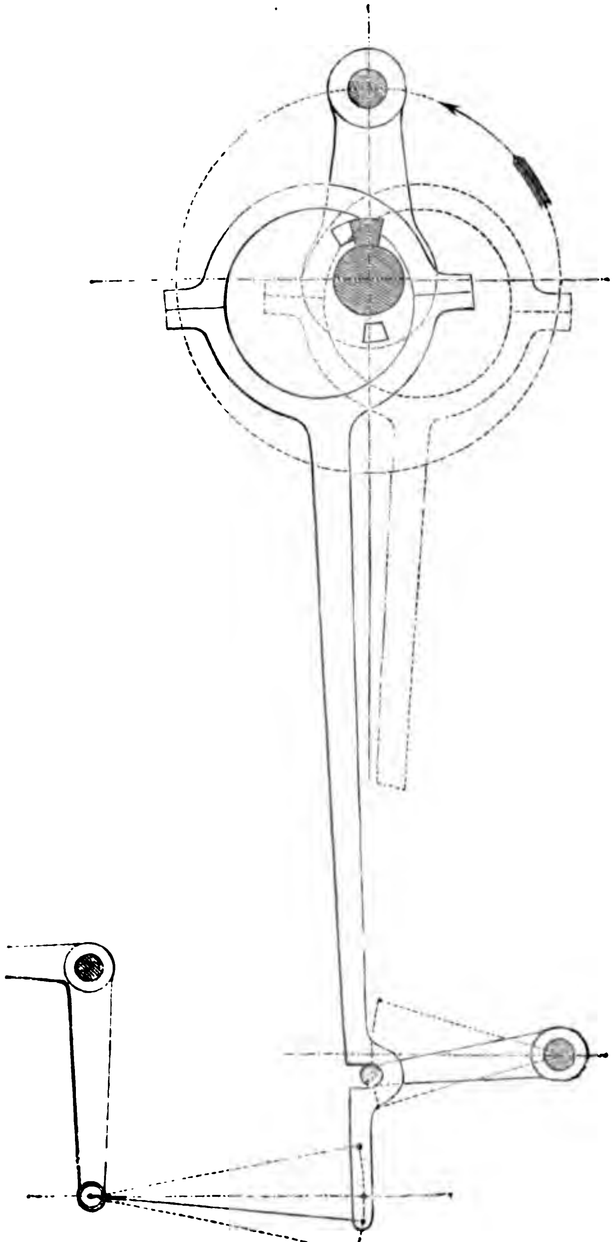


Fig. 44. Early mode of reversing.

engine as we now have. By means of a cross shaft, the rods of both these eccentrics could be held out of gear, so that the driver could work the slides by hand: then, according to the direction in which the cross shaft was moved, either the forward eccentric rod, or the backward eccentric rod, was allowed to fall into contact with the pin of the way-shaft lever, and therefore to drive the engine either backward or forward. This will readily be understood from the description, without the aid of a diagram. But, as slides became larger, and the pressure of steam greater, and the business of a railway more urgent, it was found that the working of the slides by hand was very undesirable, and therefore means were devised for reversing which dispensed with this mode of moving the slides. In both the arrangements I am about to show you, there was a double-ended lever fast on to the way-shaft and extending above and below it. In the first mode (fig. 45), this lever was made with a sort of projecting frame, having semicircular recesses, the 'gabs,' at the top and bottom, into one of which, according as the engine was to go forward or to go backward, the pin of the eccentric rod could be engaged; the recesses were widened out between the two 'gabs,' so that when the pin of the eccentric rod was being shifted from one 'gab' to the other, it was always embraced within its recess and was thus guided into the 'gab' it was about to enter.

Another arrangement, identical in principle but differing in detail, was to have one pin at the top of the double-ended lever, and one at the bottom, with an eccentric rod between them, provided with a pair of horns, the lower pair embracing the lower pin, the upper pair embracing the upper one, see fig. 46; in this arrangement again, according as the rod was made to engage either with

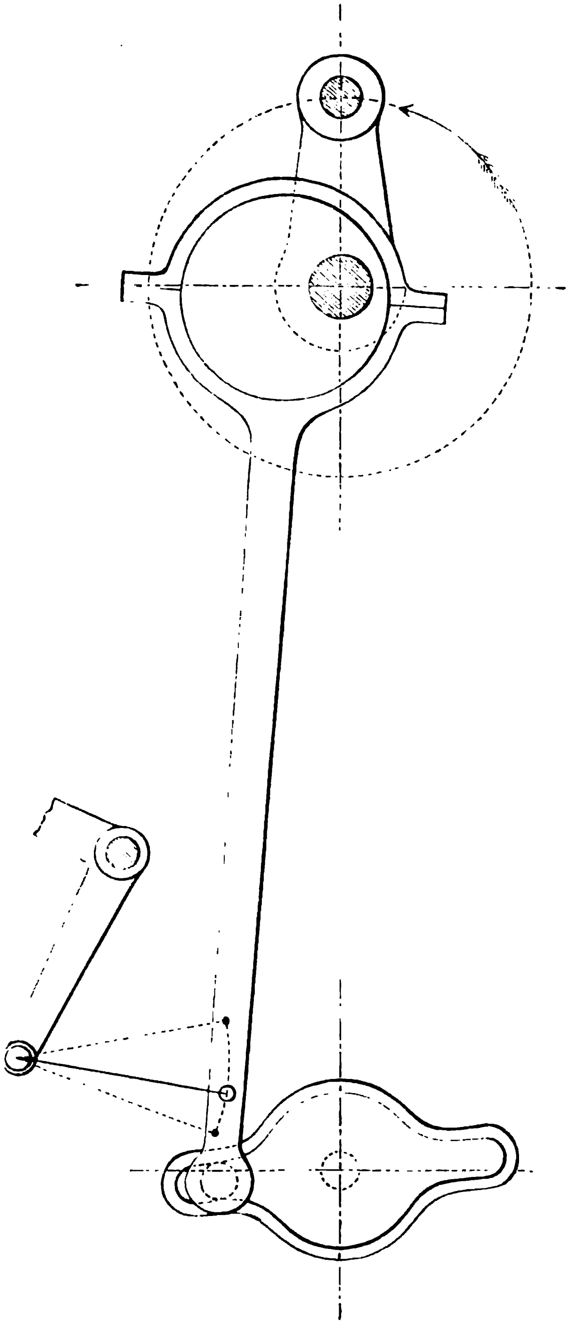


FIG. 45. Early mode of reversing.

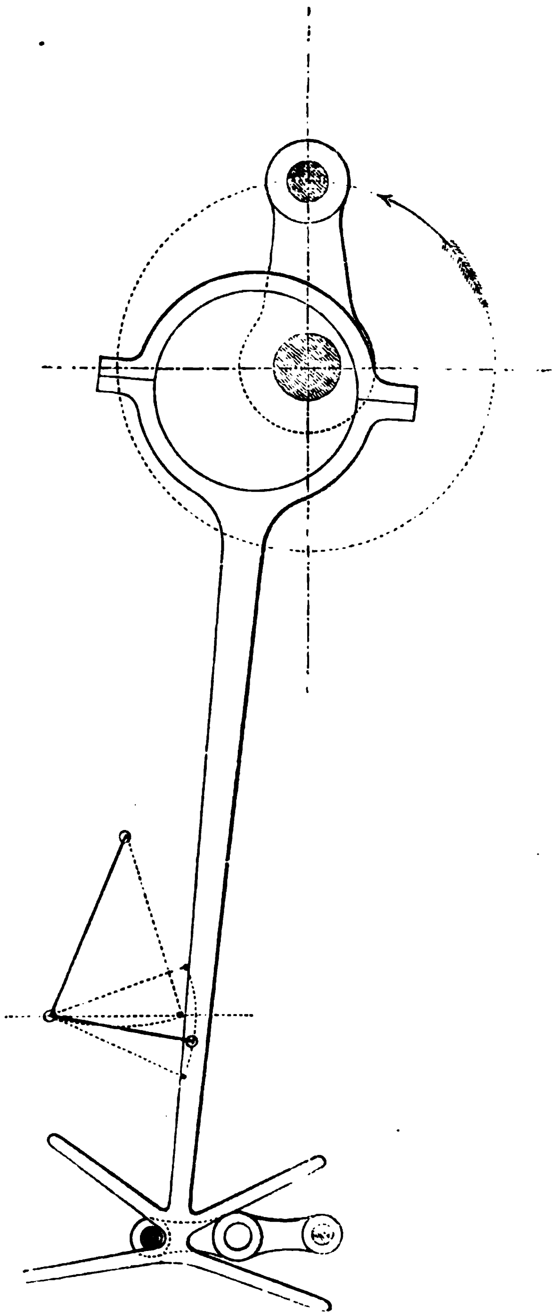


Fig. 46. Early mode of reversing.

the lower or with the upper pin, so the engine went forward or backward.

In both these arrangements there was no moving of the slides by hand, and only one eccentric was wanted for each engine, but there was this great defect, the eccentric being fixed so as to suit for both the forward and the backward gear, the slide could have practically neither lap nor lead, except to the extent afforded by the angling of the eccentric rod in moving from the top to the bottom position. The improvement in this, and the improvement which prevailed until the link was introduced, was the use of two eccentrics for each engine, as in one of the cases previously mentioned, and the furnishing of each of these eccentrics with a pair of horns, so that, without any handling of the slide, either one eccentric or the other could be forced into gear. With this arrangement it was possible to reverse the engine and to have a definite amount of lap and lead, both for forward and for backward gear, but this amount was invariable. Then came the link giving power of reversal and power of variation of expansion.

I have laid before you in these lectures imaginary diagrams constructed from considerations of the points as to where the steam is cut off, where the exhaust commences, and where compression begins, and I now wish to call your attention to enlargements of some of the actual diagrams taken to-day on the engine by which I came to Chatham, the engine which we have had an opportunity of considering together at the railway station. The lithographs you have of this engine (see fig. 43) tell you that the cylinders are 17½ inches diameter of bore, that the stroke is 2 feet 2 inches (26 inches), and that the driving wheels are 6 feet 6 inches in diameter.

Diagram fig. 47 was taken when running $29\frac{3}{4}$ miles per hour on a rising gradient of 1 in 100, with a load of 8 carriages, 1 horse box, and 2 brake vans, estimated to weigh with the passengers and luggage 105 to 110 tons, while the engine and tender and the water in the tender at the time, and the fuel, altogether were equal to 69 tons, so that the gross load moved was 175 to 180 tons; the pressure in the boiler at that time was 120 lbs.; the regulator was wide open, and the link was set to that which would have been about the second notch, had there

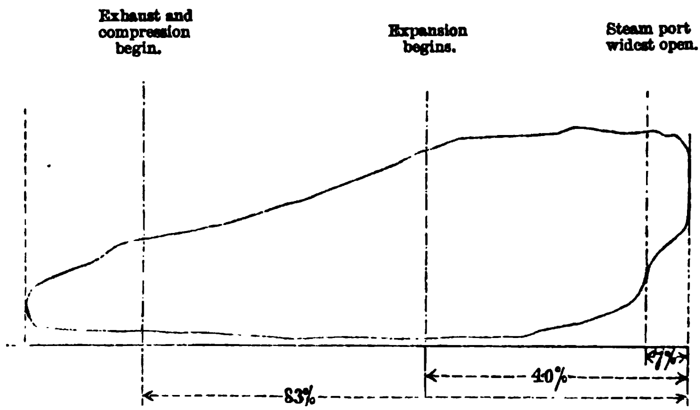


FIG. 47.

been a notch plate provided with four notches on each side of the centre. In this instance the passages were $\frac{3}{16}$ths open to the steam at the beginning of the stroke, widest open at about 7 per cent. of the stroke, and closed at about 42 per cent. of the stroke, while the exhaust from the one side of the piston and compression on the other commenced at about 83 per cent. of the stroke. These points are indicated upon the diagram by lines. You will see that these lines practically coincide with the changes in the figure; the back pressure is found to be an average of about 5 lbs.; while the mean effective pressure works out to 60·72 lbs.; taking the

speed of the piston, its diameter, and the length of stroke that I have already stated, and making the calculation in the way I have already described to you, you will find that this gives an indicated horse power of 485, equal to a gross tractive force at the edge of the wheels of 6,130 lbs., from which, if we deduct the one-sixth for the internal resistance of the engine, there remains 5,110 lbs., or a net traction of about 29 lbs. per ton of total load moved.

I will now direct your attention to the enlargement of a diagram (fig. 48) taken in your presence, a diagram with the link in mid-gear, and, as I promised, I will en-

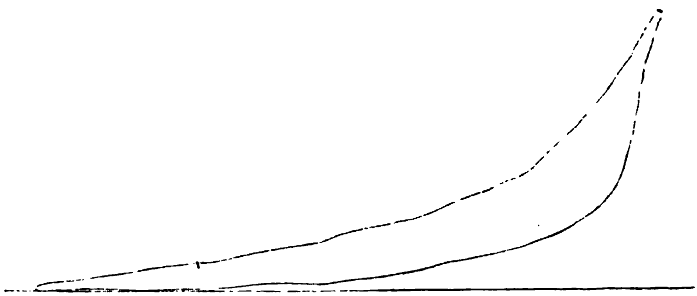


FIG. 48. Indicator diagram taken with link in 'mid gear.'

deavour to explain why it is that when the link is in this position the engine will continue to run in whichever direction it may happen to have been going at the time when the link was put into that position. As the piston is approaching the end of its stroke, the slide valve commences to open, and this occurs when the piston has still $6\frac{1}{4}$ % of its travel to make, therefore the piston has to be driven by the assistance of the other engine against the pressure of the boiler steam the whole of this $6\frac{1}{4}$%.

When this stroke is completed, however, and the return stroke commences, the piston receives the full steam pressure for the same distance of its travel as it

had had steam to oppose it, that is to say, the slide-valve which, as I have said, commenced to open when the piston had still 6¼% of its stroke to make in one direction does not close again until the piston has made 6¼% of its stroke in the other direction, and therefore the opposing and aiding forces of the steam are up to this time equal, but the cylinder now contains steam of nearly the boiler-pressure for 6¼ % of its whole length, plus that contained in the passages and in the clearance; as the piston moves onwards towards the end of its stroke this steam expands, and it continues to expand until the exhaust takes place—which under the circumstances of mid-gear is no doubt early, being at the moment when the piston has gone only ½ of its course; nevertheless, the area of the diagram contained within these two points is somewhat considerable. Thus in mid-gear, although the slide-valve allows the boiler steam to enter the cylinder adversely to the motion of the piston, yet the engine will revolve and will, as I have said, perform useful work, because the adverse action of the steam on the piston is unaccompanied by anything in the nature of expansion, while the favourable action is equal to the adverse, plus the expansive force of the steam. The foregoing reasoning, it will be seen, applies to the mere rectilinear motion of the piston, and is irrespective of any consideration of the direction of motion of the crank, and thus it is that, depending on the way in which the engine was running when the link was put into mid-notch, so will the engine continue to run.

A common mode of ascertaining the mean pressure in the cylinder is to divide the indicator diagram in the direction representing the length of the stroke of the piston into ten equal parts, to measure by scale the effective pressure at each of these parts, and to add these pressures

together, and to take the tenth of them as the mean height. A mode which is better than the foregoing is to use Amsler's planimeter, and by means of it to ascertain the area inclosed within the figure, and then to divide this area by the length of the figure in inches: the quotient will be the mean height of the diagram, from which, by the scale applicable to the particular spring in the indicator, the mean effective pressure of the steam is found.

I must not dismiss the subject of working the slides without some reference to Walschaert's gear, which is now in considerable use upon the Continent. Fig. 49 shows this arrangement. You will see that each engine has only one eccentric A (or its equivalent, a crank), and that this eccentric is placed on a line at right angles to the crank, and, as drawn, immediately below the centre B of the crank-shaft. The diagram shows an outside cylinder engine, and from the crank pin N at the right hand proceeds a return crank carrying the eccentric A. The engine is assumed to be running in the direction of the arrow. From the point A the eccentric-rod A C proceeds, and at the point C lays hold of the lower end of a link C E, which vibrates upon a fixed point D, and extends above this point D, as far as E. From this link there extends a rod H L, which at the point H has a sliding-block in the link C E, and at the point L serves as a fulcrum for the lever I L K, shortly to be described; the rod H L is suspended at the point H′, from a sling, so that by working the reversing shaft X, the end H of the rod H L can be raised or lowered in the link C E; thus the pin H may be at the height shown above the centre D, or at any greater or less height above D, or at D, or, for the purposes of reversal, below it. On the pin L vibrates, as has been said, the lever I L K, the lower end K being slotted and driven by a pin in the bottom end of the piece K K′,

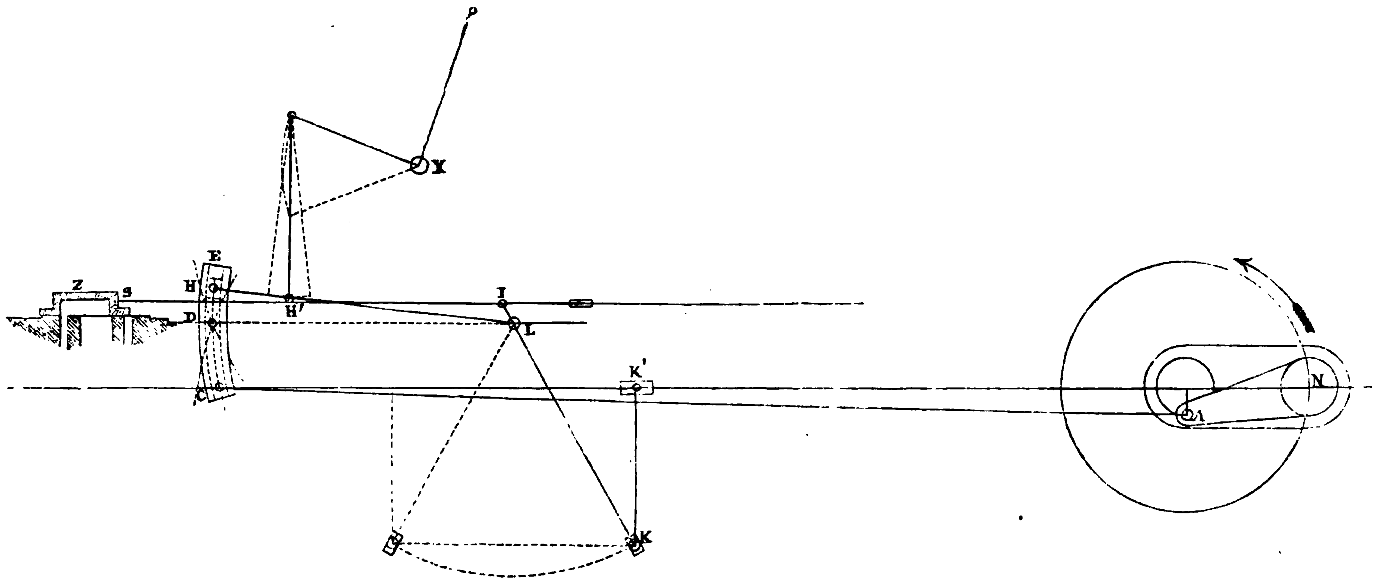


FIG. 49. Walschaert's valve gear.

rigidly pendant from the piston rod cross head, to which it is united at K′; from the point I at the top of the lever a guided rod I S goes to the slide Z.

On considering this arrangement it will be seen that the rod I S may partake of motions derived not only from the vibration of the lever I L K (which vibrations will in themselves simply be proportionate to and, but in the reverse direction, contemporaneous with, the motion of the piston), but of the motions derived from the eccentric A, the action of which through the link C E and rod H L will vary the position of the fulcrum of the lever I L K. Assuming that the link H L be lowered so that the point H be exactly opposite to the fixed centre of vibration D of the link C E, the action of the eccentric A upon the point L will be *nil*, and the motion of the slide-valve will be that due to the travel of the piston rod alone. The amount of this motion by itself is made equal to the lap plus the lead, and corresponds to the central point in the diagram of the link motion; that is to say, it is a motion derived from the point exactly in the line of the crank, and under its influence the engine would continue to travel in either direction in mid-gear as when the link motion is in mid-gear; but if the point H be raised to the position shown, then the eccentric A will impart motion to the point L (the axis of vibration of the lever I L K), and will supplement the motion given the slide-valve from I L K by its own, and will thus cause it to travel to a greater extent, will open its passage to the steam, and will cut off that steam at the periods determined by the joint action of the two sources of motion. Further, if the pin H be put somewhere between the point where it is now shown and the centre D, then the opening of the passage will become less and the cut-off will be earlier; but if the pin H be put below the centre D, then on fol-

lowing through the motions of the various levers it will be found that the engine will run in the reverse direction.

Although so very dissimilar in appearance the Walschaert gear is, after all, only the link motion in disguise. For in the Walschaert gear, as in the link motion, two eccentrics in truth are employed, the one the actual eccentric A at right angles to the crank, the other the reduced travel, derived from the piston rod, which, being controlled by the crank, gives precisely the same motion as would be obtained from an eccentric of a throw equal to the reduced motion, and having its centre situated in the line of the crank itself. And, as in the case of the link motion, the effect of the two eccentrics, wherever the link was placed, might be obtained from a single eccentric suitably placed on the line x y (see figs. 39A, A to H). So, similarly, in the Walschaert gear any of the effects of the combined action of the eccentric and of the piston rod, can be obtained by a single eccentric properly placed in the line x y (see diagram, fig. 50), where x y is placed so far from the vertical centre line through the shaft, as represents the half of the motion communicated by the piston rod to the slide Z; that is, equal to half the lap and lead, while the distance from the horizontal centre line to I represents the half of the motion communicated by the eccentric A to the point L of the lever I L K, when H is at the extreme upward position in the vibrating link C E.

A single eccentric, having its centre at 1 (see fig. 50), will be found to give precisely the same motions, to the slide Z, as would be obtained from the combination of the piston rod movement, and of the eccentric A, when the block H was at the topmost position in the vibrating link C E. Similarly, a single eccentric having its centre on the line x y at 2 (see fig. 50), which is midway between 1

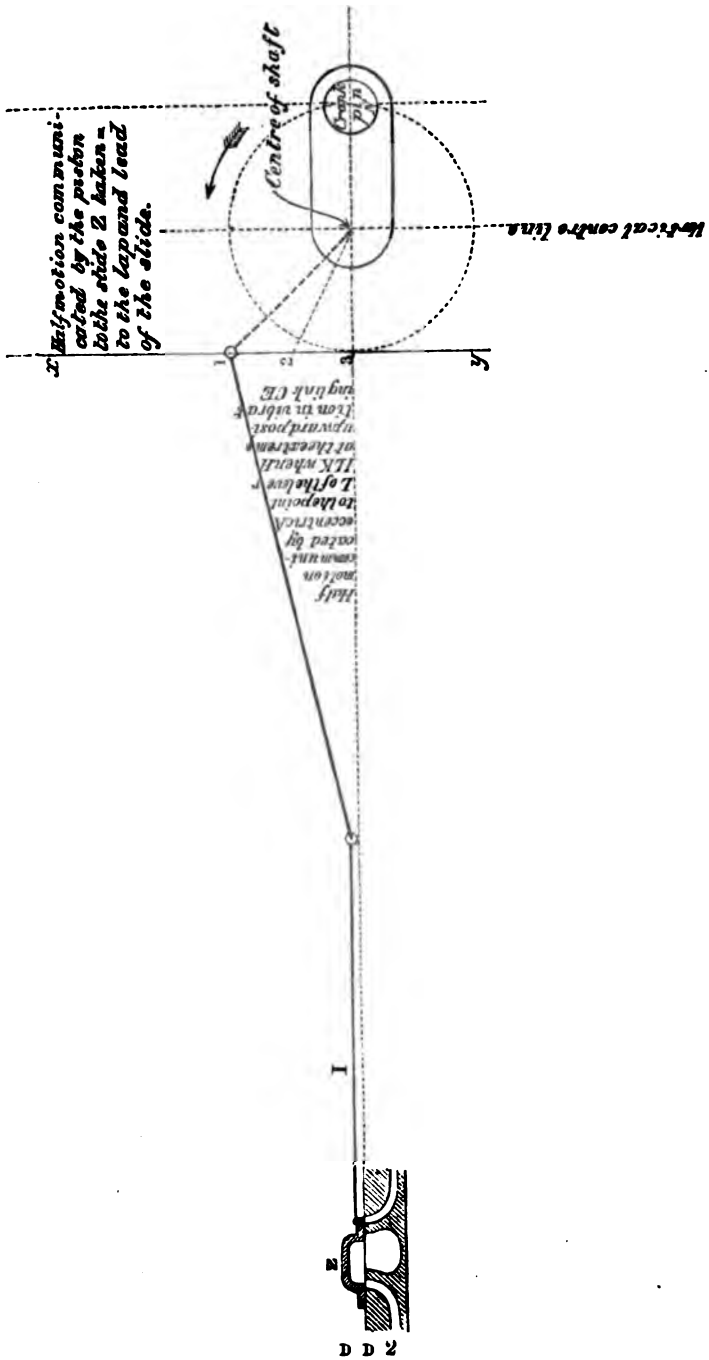


FIG 50. To illustrate Walschaert's valve gear.

and the horizontal centre line, would give the same motions to the slide Z as would be given by the combined action of the piston rod and of the eccentric A of the Walschaert gear, when the block H was lowered midway between its first position in the vibrating link C E and the centre D of that link. Finally, a single eccentric placed on the line $x\ y$ at 3—that is, on the horizontal centre line—would obviously give the same motion as the two implements, the piston rod and the eccentric A would give when the block H was lowered opposite to the centre D of the vibrating link C E, the motion would then obviously be only that obtained from the piston rod.

With the exception that occasionally it may be very convenient to dispense with the space occupied by two eccentrics out of the four, there appears to be no reason why the Walschaert gear should be used in preference to the link motion.

Before I dismiss (as time now compels me to do) this important question of the movements of the slide valve, I will call your attention to diagram fig. 51, with its accompanying table, fig. 52. Diagram 51 affords graphically, in percentages of the stroke, information as to the point of suppression or cut off, of exhaust, of release, of the period of greatest opening, and of the amount of that opening, for both ends of the cylinder, in the four different notches of forward, and of backward gear. By the aid of this diagram one is enabled readily to appreciate the behaviour of the valve under the varying circumstances stated, or reference may be made to fig. 52, where similar information is recorded in figures.

Having considered, at perhaps too great length, the modes of varying the expansion, and of giving reversal, it may be as well here to call your attention to the manipulation of the engine when under way.

The driver has before him a handle by which he works the steam regulator: this consists commonly of a sliding valve, opening, or closing the steam outlet, from the boiler, to the cylinders. Formerly the speed of the engine was controlled by the greater or less amount of this opening, thus reducing or 'wiredrawing' the pressure of the steam; but now that the link motion enables the expansion to be varied at will, the regulator, as already stated, should be kept wide open, and, to economise fuel, the speed should be controlled by varying the amount of expansion.

The mode of working the link by lever or by screw has already been fully described. To regulate the fire, the driver has under his control the levers of the ash-pan dampers or damper, as the case may be, by which he can determine the quantity of air which shall pass through the fuel, and he has also a means of varying the amount of air which goes in at the fire door above the fuel. He has also in certain engines, as in the one you saw this morning, another lever by which he can alter the area of the aperture of the blast pipe, thereby varying the intensity of the blast; and, as already explained, he has, for use at those times when the waste steam blast is off, another handle, by the movement of which he can discharge free steam from the boiler up the chimney through an auxiliary blast pipe; he can also, by means of other handles, put on the injector to feed the boiler. For slippery rails, he has the levers to the sand-boxes within reach, by the use of which sand can be poured down in front of the wheels. He has also the safety valve lever; and he has the pressure-gauge, to indicate the pressure of the steam. He has the glass water gauge, and the gauge cocks, to show the level of the water; and he has drain cocks from the two ends of the cylinders by

which water of condensation that forms at first starting, or any water which has primed over into the cylinders, while running, can be got rid of. Further he has a draw-off cock and a scum cock from the boiler, while to give an alarm and for signalling he has the steam whistle. In ordinary engines he is provided with a screw

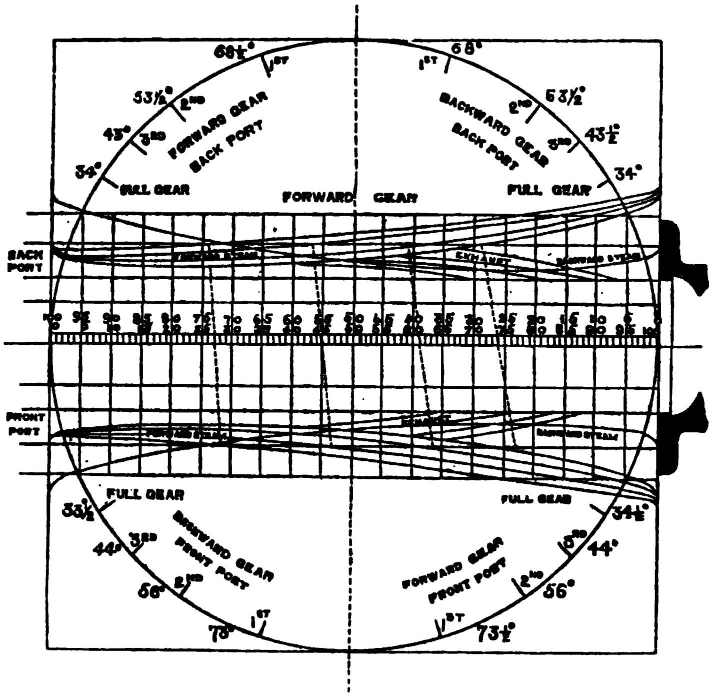


Fig. 51.

LONDON CHATHAM AND DOVER RAILWAY.
Engines Class B. Distribution curves.

hand-break, operating upon the wheels of the engine if it be a 'tank' engine (but rarely in other cases), or upon the wheels of the tender if it be a tender engine. New engines, however, are generally fitted as was the one which you saw this morning with a steam-break, which is applied to the engine wheels. Further, if the

tender have the Ramsbottom apparatus, the driver has

FIG. 52.

FORWARD GEAR

Notches	Travel	Lead B	Lead F	Opening B	Opening F	Suppression B	Suppression F	Release B	Release F	Angle of Crank B	Angle of Crank F
Full	$4\frac{1}{16}''$	$\frac{3}{32}''$	$\frac{3}{16}''$	$1\frac{1}{16}''$	1	71	76	90	$92\frac{1}{2}$	34	$34\frac{1}{2}$
3rd	$3\frac{15}{32}''$	$\frac{5}{32}''$	$\frac{1}{4}''$	$\frac{3}{4}''$	$\frac{23}{32}''$	59	63	$84\frac{1}{2}$	88	43	44
2nd	$2\frac{21}{32}''$	$\frac{3}{16}''$	$\frac{5}{16}''$	$\frac{15}{32}''$	$\frac{1}{2}''$	43	$46\frac{1}{2}$	77	81	$53\frac{1}{2}$	56
1st	$2\frac{11}{16}''$	$\frac{7}{32}''$	$\frac{11}{32}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$24\frac{1}{2}$	$27\frac{1}{2}$	65	69	$68\frac{1}{2}$	$73\frac{1}{2}$
Difference		—	—	$\frac{1}{16}''$	—	—	5	—	$2\frac{1}{2}$	—	$\frac{1}{2}$
		—	—	$\frac{1}{32}''$	—	—	4	—	$3\frac{1}{2}$	—	1
		—	—	—	$\frac{1}{32}''$	—	$3\frac{1}{2}$	—	4	—	$2\frac{1}{2}$
		—	—	—	$\frac{1}{16}''$	—	3	—	4	—	5

BACKWARD GEAR

Notches	Travel	Lead B	Lead F	Opening B	Opening F	Suppression B	Suppression F	Release B	Release F	Angle of Crank B	Angle of Crank F
Full	$4\frac{3}{32}''$	$\frac{3}{32}''$	$\frac{3}{16}''$	$1\frac{3}{32}''$	1	$71\frac{1}{2}$	76	90	93	34	$33\frac{1}{2}$
3rd	$3\frac{15}{32}''$	$\frac{5}{32}''$	$\frac{1}{4}''$	$\frac{3}{4}''$	$\frac{23}{32}''$	59	$63\frac{1}{2}$	85	88	$43\frac{1}{2}$	44
2nd	$2\frac{21}{32}''$	$\frac{3}{16}''$	$\frac{5}{16}''$	$\frac{15}{32}''$	$\frac{1}{2}''$	43″	46	$76\frac{1}{2}$	81	$53\frac{1}{2}$	56
1st	$2\frac{11}{16}''$	$\frac{7}{32}''$	$\frac{11}{32}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$24\frac{1}{2}$	27	65	$69\frac{1}{2}$	68	73
Difference	—	—	—	$\frac{3}{32}''$	—	—	$4\frac{1}{2}$	—	3	$\frac{1}{2}$	—
	—	—	—	$\frac{1}{32}''$	—	—	$4\frac{1}{2}$	—	3	—	$\frac{1}{2}$
	—	—	—	—	$\frac{1}{32}$	—	3	—	$4\frac{1}{2}$	—	$2\frac{1}{2}$
	—	—	—	—	$\frac{1}{16}''$	—	$2\frac{1}{2}$	—	$4\frac{1}{2}$	—	5

Diameter of Cylinder, $17\frac{1}{2}'' \times 26''$ stroke.
Angle of forward eccentric pulley, 103°.
Throw of eccentric pulley, $6\frac{1}{2}''$.

Length of connecting rod, 6′ 1″.
Angle of backward eccentric pulley, $103\frac{3}{4}$°.
Lap of valve, 1″.

the lever, to his hand, which controls the position of the

pendant pipe. Before closing this enumeration of the apparatus for manipulating the engine, one should just refer to the question of lubrication. In a locomotive all the bearings are fitted with well-designed oil-cups provided with capillary tubes and with screw or spring covers; the internal lubrication is made by close-top lubricators, which introduce drops of grease slowly into the steam as it passes to the cylinders.

Leaving now the consideration of the locomotive as an engine, and viewing it as a carriage, the first point to be considered is—the distribution of the weight. As we have already found, attention must be paid to the imposing upon the wheels which drive, a very considerable weight; but on the other hand the leading wheels must not be too lightly loaded, or there will be the danger of the engine leaving the rails. With single driving wheels, the centre of gravity of the engine as a whole is very commonly from 1 to 2 feet in front of the crank axle. In a goods engine with all six wheels coupled, the centre of gravity may be over the centre axle, while in the type of engine which you saw this morning, where four wheels are coupled, the centre of gravity is generally about 1 foot in front of the crank axle. And with such a distribution of the weight as this gives, the four driving wheels appear to be sufficiently loaded.

The evil effects of the irregularities of the road are, as we all know, compensated for by the springs. I am not aware that the rules for the strength of these, given many years ago, have been superseded. These are—for the elasticity of the springs—

$$\frac{\text{Span in inches}^3}{\begin{matrix}\text{Thickness of each plate}^3 \\ \text{in sixteenths}\end{matrix} \times \begin{matrix}\text{No. of} \\ \text{plates}\end{matrix} \times \begin{matrix}\text{Breadth} \\ \text{in ins.}\end{matrix}} \times 1\cdot 66 = \text{deflection in sixteenths for each ton of load.}$$

And for the safe working load—

$$\frac{\text{Width in ins.} \times \text{No. of plates} \times \text{Thickness of each plate in sixteenths}^2}{\text{Span in inches} \times 11\cdot 3} = \text{Safe working load in tons.}$$

But the efficiency of the spring can be increased, and the amount of oscillation in the engine while running can be very much lessened, by the use of what are called 'balance beams,' similar to those shown at A in the diagram fig. 10A. These beams being placed between two pairs of wheels, say the crank axle wheels and the hind or trailing wheels, convert a six-wheeled carriage into, practically, a four-wheeled one, because the only point of attachment to the engine-frame for the four wheels which are connected by the balance beam, is the pin on which that beam vibrates. If one considers how difficult it would be with a four-wheeled carriage, having its centre of gravity between its two pairs of wheels, to set up a pitching motion, and how easy it would be so to do with a six-wheeled carriage, having its centre of gravity immediately over the centre axle, one can readily see that an arrangement which, while obtaining the distribution of the total weight of the engine, over six points of support upon the rails, nevertheless causes the engine to stand as though it were upon two pairs of wheels only, is one which should add to stability in running: this great advantage is attained, as I have before said, by the use of the balance beam. Moreover the evil effect of any irregularity in the rail is diminished as regards its being communicated to the engine, because the irregularity does not lift the engine directly, as it would do were the engine supported immediately over the wheel, but lifts it through the fulcrum of the beam, and thus diminishes the motion which has been communicated to the ends of that beam. These considerations point to the desirability of the use of balance beams; they have been extensively employed in America, and are also used in England; but there are certain practical difficulties connected with their employment, which cause many loco-

motive engineers of great eminence to be very chary in adopting them.

The conditions we have as yet considered deal only with the engine, as a carriage, when running upon a straight road; but on railways the engine has to go round curves—curves of considerable radius, it is true, when compared with those on ordinary roads, but of small radius when the length of wheel base, and the rigid nature of the carriage, is considered. The first evil to be guarded against in going round a curve is the risk of the engine leaving the rails by the centrifugal action. This, as you know, is provided against by that which is called the super-elevation of the outer rail. I may here perhaps be allowed to give an extremely simple rule useful for mental calculation upon this point. One mile an hour speed, round one chain radius, can be satisfied by the super-elevation of one sixteenth of an inch, when the line is of the $4' \, 8''\frac{1}{2}$ gauge, these proportions of course varying as the square of the speed, and inversely as the radius. If you apply this to say 30 miles an hour, round a 30 chain curve, you will find that you get thirty-sixteenths, or one and seven-eighths. Some of the rules commonly given would make this a little over 2 inches, but the agreement is near enough to make a rule of this kind, which deals entirely with unities and is so easily worked, one worth remembering. But the super-elevation deals only with one of the difficulties experienced in going round curves. The next great difficulty, to be considered, is the difference that exists between the circumferential travel of the wheel on the inner side of the curve, and that of the wheel on the outer side. We know that compensation is sought for this difference by making the wheels conical, and by having a greater width between the inner edges of the two rails than between the outer edges of the flanges of

a pair of wheels, so that the larger part of the cone may operate upon the outer curve, and the smaller part upon the inner. Very commonly engines are made with no other provision than this, and the allowing a certain amount of endway play in the axles; under these circumstances

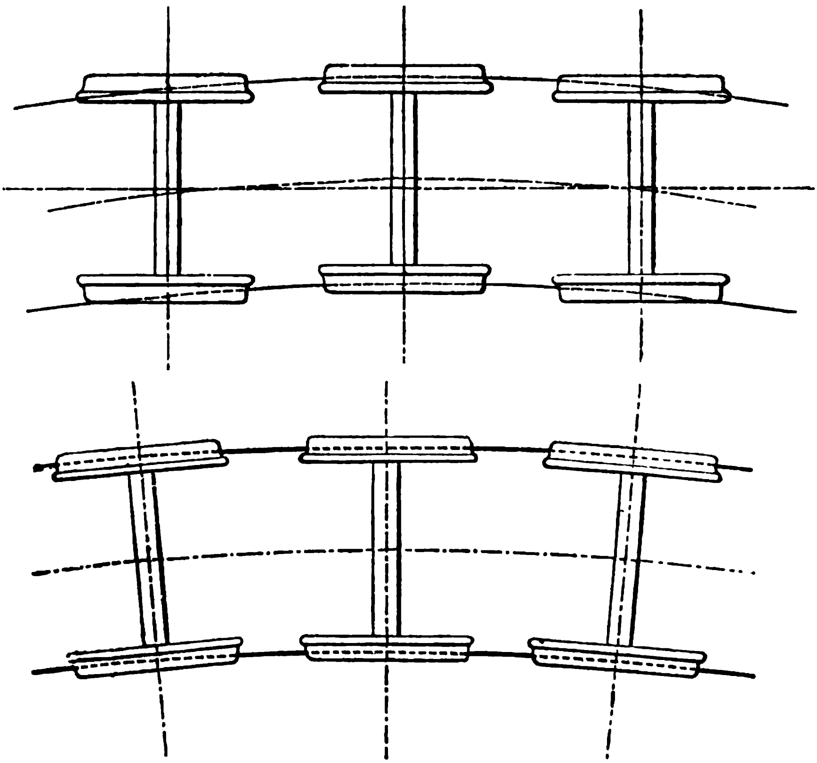


FIG. 53. Three fixed and three radial axles.

a six-wheeled engine, when put upon a curve, would have its wheels standing as shown in the top figure of the diagram (fig. 53), that is, with all three axles parallel, but with the centre of the centre pair of wheels moved somewhat sideways in relation to the centre of the end pair of wheels, and thus to allow the carriage to accom-

modate itself to the curvature of the rails. But these axles being parallel the one to the other, the centre one alone can radiate. The result of this non-radiation is to produce a tendency for the axles to move endways, the forward axle striving to go outside the curve, and the hinder axle striving to go inside, and both tending to turn the engine round its centre and to cause it to leave the line; moreover, the 'rub' produced between the tyres and the rails is very considerable, and is quite equal, as I showed in some remarks of mine a good many years ago at the Civil Engineers, to the 'rub' produced by the difference between the diameter of the wheels on the outside rails and that of the wheels on the inside rails. At that time I made a rough model to show the effect of a weighted roller bearing on a curved path radially, and then of the same roller, bearing on the same curved path non-radially. I have the model here, but I doubt whether the action of it can be seen, but I will show it after the Lecture.* The utility of radiation in all the axles is therefore very great, both on the score of safety and on the score of wear and tear. Perfection in this respect would be obtained if we could cause the three axles of the carriage of which we are speaking to assume the position shown in the bottom part of Fig. 53. More especially does this ability to radiate become necessary with the large and powerful engines of the present day, which have a wheel base, such as that we have seen on our engine this morning, of nearly as much as 21 feet.

Very early in the history of locomotives, attempts were made to cure this difficulty of non-radiation by using that which is in truth the 'perch pin' of an ordinary road carriage at the front part of the engine, so as to support

* See Vol. xxvi. *Trans. Civil Engineers*, p. 358.

the engine upon a small four-wheeled truck or 'bogey' capable of movement about this perch pin. Such a construction admitted of the approach to radiation of the axles of the bogey, but you will see that it did not overcome another difficulty resulting, in six-wheeled engines, from passing round curves. Assuming that the crank axle wheel and the hind wheel of a locomotive are placed, as they may be, upon a curve touching it at the four points, this position would project the centre line of the engine tangentially, so that at the front end, where the perch pin would be

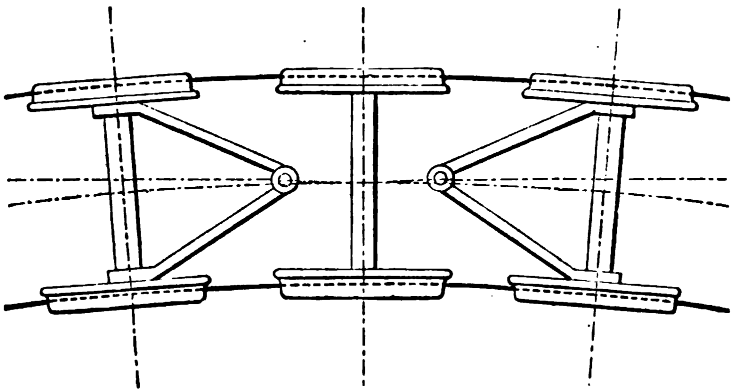


FIG. 54. 'Bissel Bogey' applied to a six-wheeled carriage.

placed, that centre line would be a considerable distance outside the centre of the track. But on an ordinary bogey the perch pin must be (clearance apart) in the centre of the track, and therefore the adjustment must be made by the endway play of the various axles, and the clearance of the flanges. A consideration of the foregoing proves that not only is radiation of the axles needed, but that a variation sideways between the centre of the bogey and the centre of the engine is demanded. This is satisfied by the 'Bissel bogey,' a drawing of which is exhibited in diagram fig. 54. Here the perch pin is a long way from the axle, allowing it to accommodate itself very nearly exactly to the needs of the curve

To prevent the bogey going beyond the required limits, and to cause it to 'centre' itself when the line becomes straight, inclines on which the weight of the engine is taken are employed, or springs are used.

The same end is attained by various arrangements, and notably by an extremely excellent one designed by Mr. Webb, of Crewe, in which the radius rod of the single axle is dispensed with and a curved path is substituted. I very much regret that time has not permitted me to give you diagrams and descriptions of these modes. I will now, however, ask your attention to the construction of bogey used in the engine which you have seen this morning—the design being that of Mr. Adams, of the Great Eastern Railway (see fig. 55). In this there is a perch pin as before, provided with a rounding end, so as to admit of the bogey carriage being twisted or of its standing on a different plane from that on which the other wheels stand, and thus it can accommodate itself to the super-elevation of the rail at the commencement of a curve. Between the engine, and the bogey frame there is a large bed of india-rubber, as much as two feet diameter, which supports the weight, and by its friction gives great steadiness. Thus far radiation, and not lateral movement, is provided for, but the two axles of the bogey carriage, instead of being attached directly to the frame, containing the hole which embraces the perch pin, are attached to an outer frame which can slide upon the one which contains the perch pin: it is in this manner the required lateral movement is secured.

To prevent this lateral movement from being excessive, and to cause the bogey always to have a tendency to return to the centre line of the engine, there are two powerful india-rubber side springs (under initial tension), and always pressing the bogey carriage towards the centre line of the engine.

I will now call your attention to a mode of bringing

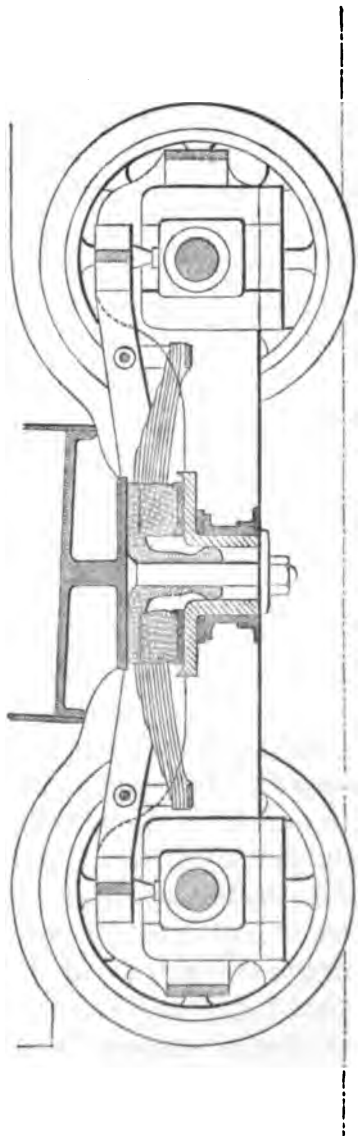


Fig. 55. Adams' bogey.

a train to a standstill, or of reducing its speed upon an in-

cline, which has been very little used in England, although it is extensively employed in some parts of France. I allude to the 'Contre-vapeur' system introduced by Le Chatelier, a paper on which (written by Dr. Siemens) is published in the 'Transactions of the Institution of Mechanical Engineers' for the year 1870; appended to this are the records of experiments made by me on the subject, and I will refer you to this paper and to its appendix for full information. But I must say here that the system, which might be thought a very obvious one, is simply the reversal of the engine while the regulator is left wide open. The result is to cause the pistons to pump back into the boiler, the steam which has entered the cylinders from the boiler, after a large portion of the stroke has been made. No doubt long before Le Chatelier's time, on emergencies, and to avoid collisions, engines had been reversed with steam on, but the plan was only adopted on an emergency, and was thus sparingly adopted, because the heat developed in the cylinders, was sufficiently great to cause the surfaces to become cut and scored, and to burn the packing in the stuffing boxes; moreover, it was thought, although, as I believe, entirely upon insufficient grounds, that the parts of the engine were strained in the operation. Le Chatelier's invention consisted in injecting into the cylinders so much water from the boiler as would suffice to absorb the heat generated, and to keep the cylinders down to the temperature due to the pressure of the boiler steam. This plan has been found in France to act perfectly, and has not given rise, as was anticipated, to any difficulty, such as is experienced when water primes over from the boiler into the cylinder, because, as I have said, the heat developed has been enough to vapourise the water, and to leave the cylinders with steam in

them and not with water. The effect produced will be best understood by a reference to the enlarged indicator diagrams (figs. 56 and 57) on the wall. From them you will see that during about the first half of the stroke of the piston there is nothing to oppose its motion, except a slight compression of the air in the cylinder;

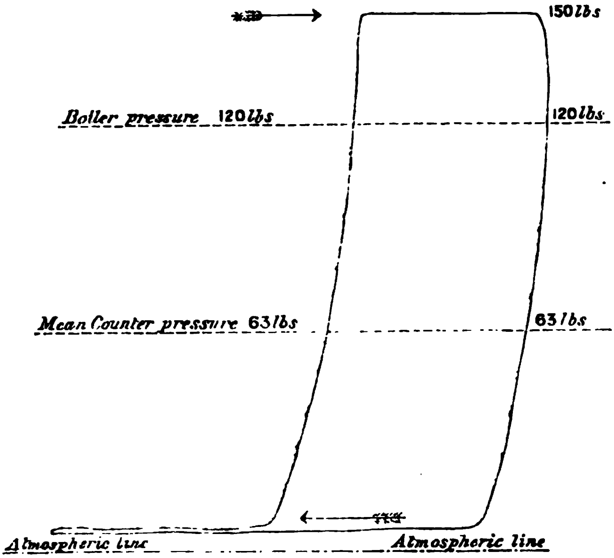


FIG. 56. Counter-pressure diagram taken at a speed of 40 miles an hour.

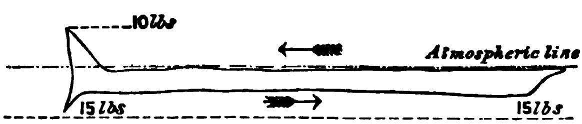


FIG. 57. Vacuum diagram; speed 8 to 10 miles an hour.

but after this the steam valve opens, and then the further progress of the piston is made against the pressure of the boiler steam, which by the advance of the piston is driven back into the boiler. The value of this retardation can be estimated in the ordinary manner from the area of the diagram. In the case to which these diagrams refer,

which was that of a locomotive having outside cylinders 17 inches diameter by 22 inches stroke, with driving wheels of 6 feet 6 inches diameter; the value of the pressure upon the diagram amounts to as much as 1·82 tons at the circumference of the driving wheels, or equal by itself to the bringing up of the train which weighed gross 160 tons in 1,575 yards from a speed of forty miles an hour. If, however, the retardation due to the friction of the train and the resistance of the air, equal to 1·35 tons, be added to the 1·82 tons above stated, it will be found there is a total retardation at the circumference of the driving-wheels of 3·17 tons, equal to the bringing up of the train in a distance of 904 yards instead of 1,575 yards. From the experiments being then conducted, it appeared that, by the use of this system, the trains may be brought to rest at the various stations at which they stop in just about the same time as by the application of the ordinary tender and guard's break, and they would be brought to rest without any of the wheels being skidded, and, therefore, without any fear of the tyres having flats worn upon them. I think the system an admirable one for the ordinary working of trains. I think it an admirable one for working trains in going down inclines, but I am sure it is not one which would supersede continuous breaks, as applied to all vehicles. Before leaving this subject I wish to call your attention to a very curious result recorded by the diagram—a result that was entirely unexpected, and that, when first obtained, was inexplicable.

You will observe that the pressure of steam in the cylinder was very much higher than that in the boiler. The first idea was that the indicator was out of order, and that the springs were wrong, but these on being tested were found to be perfectly accurate. The next idea was that

the excess represented the pressure necessary to drive the steam back into the boiler, but this obviously was not so, because an ordinary diagram, taken when the engine was working ahead, showed that nothing like that pressure was required to drive the steam from the boiler to the engine, and therefore made it clear, that such a pressure could not be wanted to drive the steam from the engine to the boiler. The explanation of the phenomenon is no doubt this. In the particular engine that was used, the steam regulator was at the fire box: the boiler was fitted with a long internal pipe which conveyed the steam to the cylinders in the smoke box: when the steam entered the cylinder it found half the cubic contents of that cylinder to fill, which you will see it did almost immediately, the line indicating the filling being very nearly vertical. Thus the steam rushed along the internal boiler pipe with enormous velocity, but on filling the cylinder up to the pressure, the momentum of the steam in the pipe remained, and that momentum you will find, if you include in your calculation the weight of the steam, the size of the pipe, and the contents of the vessel to be filled, was far more than sufficient to give the increased pressure shown on the diagrams, the fact being that that indication was limited, not by the actual pressure, but by the range of the spring that happened to be in the indicator.

I mention this as the first instance I know of, of the kind, and as showing, that you may have in an elastic fluid like steam, a similar action to that which you have in the nearly non-elastic fluid water when employed in the water ram; there is no doubt whatever, but that in the case of these experiments, the steam acted as a steam ram.

Time does not admit of my saying anything about

steam engines on common roads, nor of the Fell system, both of which subjects in the outset I had hoped to touch upon, and I must now bring this short course of lectures to a conclusion.

Of necessity the account I have been able to give you of the locomotive is very imperfect: locomotive literature now extends to several large volumes, and doubtless has not yet reached its limits; it has been impossible, therefore, in the three meetings we have had, to do more than give a sort of sketch of some of the leading features, but I trust that the sketch has been sufficiently complete to make those features clear to you, and also to assist you in understanding, as each instance may come under observation, the principles and details of that particular instance, and thus to enable you to regard them with appreciation. I have to thank you for your kindness and the close attention that you have paid to me, and I beg leave to assure you, that, whatever may be the value to you of the lectures you have heard, the delivery of them has been, owing to your kindness, a great pleasure to myself.

INDEX.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

GENERAL LISTS OF WORKS

PUBLISHED BY

MESSRS. LONGMANS, GREEN & CO.

HISTORY, POLITICS, HISTORICAL MEMOIRS, &c.

History of England from the Conclusion of the Great War in 1815. By SPENCER WALPOLE. 8vo. VOLS. I. & II. 1815-1832 (Second Edition, revised) price 36*s*. VOL. III. 1832-1841, price 18*s*.

History of England in the 18th Century. By W. E. H. LECKY, M.A. VOLS. I. & II. 1700-1760. Second Edition. 2 vols. 8vo. 36*s*.
VOLS. III. & IV. are in the press.

The History of England from the Accession of James II. By the Right Hon. Lord MACAULAY.
STUDENT'S EDITION, 2 vols. cr. 8vo. 12*s*.
PEOPLE'S EDITION, 4 vols. cr. 8vo. 16*s*.
CABINET EDITION, 8 vols. post 8vo. 48*s*.
LIBRARY EDITION, 5 vols. 8vo. £4.

The Complete Works of Lord Macaulay. Edited by Lady TREVELYAN.
CABINET EDITION, 16 vols. crown 8vo. price £4. 16*s*.
LIBRARY EDITION, 8 vols. 8vo. Portrait, price £5. 5*s*.

Lord Macaulay's Critical and Historical Essays.
CHEAP EDITION, crown 8vo. 3*s*. 6*d*.
STUDENT'S EDITION, crown 8vo. 6*s*.
PEOPLE'S EDITION, 2 vols. crown 8vo. 8*s*.
CABINET EDITION, 4 vols. 24*s*.
LIBRARY EDITION, 3 vols. 8vo. 36*s*.

The History of England from the Fall of Wolsey to the Defeat of the Spanish Armada. By J. A. FROUDE, M.A.
POPULAR EDITION, 12 vols. crown, £2. 2*s*.
CABINET EDITION, 12 vols. crown, £3. 12*s*.

The English in Ireland in the Eighteenth Century. By J. A. FROUDE, M.A. 3 vols. crown 8vo. 18*s*.

Journal of the Reigns of King George IV. and King William IV. By the late C. C. F. GREVILLE, Esq. Edited by H. REEVE, Esq. Fifth Edition. 3 vols. 8vo. price 36*s*.

The Life of Napoleon III. derived from State Records, Unpublished Family Correspondence, and Personal Testimony. By BLANCHARD JERROLD. With numerous Portraits and Facsimiles. 4 vols. 8vo. £3. 18*s*.

The Early History of Charles James Fox. By GEORGE OTTO TREVELYAN, M.P. Fourth Edition. 8vo. 6*s*.

The Speeches of the Rt. Hon. the Earl of Beaconsfield, K G. Selected and arranged, with Explanatory Notes and a Preface, by T. E. KEBBEL. 2 vols. 8vo. 32*s*.

The Constitutional History of England since the Accession of George III. 1760–1870. By Sir THOMAS ERSKINE MAY, K.C.B. D.C.L. Sixth Edition. 3 vols. crown 8vo. 18*s.*

Democracy in Europe; a History. By Sir THOMAS ERSKINE MAY, K.C.B. D.C.L. 2 vols. 8vo. 32*s.*

Introductory Lectures on Modern History delivered in 1841 and 1842. By the late THOMAS ARNOLD, D.D. 8vo. 7*s.* 6*d.*

On Parliamentary Government in England. By ALPHEUS TODD. 2 vols. 8vo. 37*s.*

Parliamentary Government in the British Colonies. By ALPHEUS TODD. 8vo. 21*s.*

History of Civilisation in England and France, Spain and Scotland. By HENRY THOMAS BUCKLE. 3 vols. crown 8vo. 24*s.*

Lectures on the History of England from the Earliest Times to the Death of King Edward II. By W. LONGMAN, F.S.A. Maps and Illustrations. 8vo. 15*s.*

History of the Life & Times of Edward III. By W. LONGMAN, F.S.A. With 9 Maps, 8 Plates, and 16 Woodcuts. 2 vols. 8vo. 28*s.*

The Historical Geography of Europe. By E. A. FREEMAN, D.C.L. LL.D. Second Edition, with 65 Maps. 2 vols. 8vo. 31*s.* 6*d.*

History of England under the Duke of Buckingham and Charles I. 1624–1628. By S. R. GARDINER, LL.D. 2 vols. 8vo. Maps, 24*s.*

The Personal Government of Charles I. from the Death of Buckingham to the Declaration in favour of Ship Money, 1628–1637. By S. R. GARDINER, LL.D. 2 vols. 8vo. 24*s.*

The Fall of the Monarchy of Charles I. 1637–1649. By S. R. GARDINER, LL.D. VOLS. I. & II. 1637–1642. 2 vols. 28*s.*

Bosco's Compendium of Italian History from the Fall of the Roman Empire. Translated from the Italian, and continued to the Present Time, by J. D. MORELL, M.A. LL.D. With 8 Illustrations. Royal 8vo. 7*s.* 6*d.*

Popular History of France, from the Earliest Times to the Death of Louis XIV. By Miss SEWELL. Crown 8vo. Maps, 7*s.* 6*d.*

A Student's Manual of the History of India from the Earliest Period to the Present. By Col. MEADOWS TAYLOR, M.R.A.S. Third Thousand. Crown 8vo. Maps, 7*s.* 6*d.*

Outline of English History, B.C. 55–A.D. 1880. By S. R. GARDINER, LL.D. Pp. 484, with 96 Woodcuts and Maps. Fcp. 8vo. price 2*s.* 6*d.*

Waterloo Lectures; a Study of the Campaign of 1815. By Col. C. C. CHESNEY, R.E. 8vo. 10*s.* 6*d.*

The Oxford Reformers—John Colet, Erasmus, and Thomas More; a History of their Fellow-Work. By F. SEEBOHM. 8vo. 14*s.*

History of the Romans under the Empire. By Dean MERIVALE, D.D. 8 vols. post 8vo. 48*s.*

General History of Rome from B.C. 753 to A.D. 476. By Dean MERIVALE, D.D. Crown 8vo. Maps, price 7*s.* 6*d.*

The Fall of the Roman Republic; a Short History of the Last Century of the Commonwealth. By Dean MERIVALE, D.D. 12mo. 7*s.* 6*d.*

The History of Rome. By WILHELM IHNE. 5 vols. 8vo. price £3. 17*s.*

Carthage and the Carthaginians. By R. BOSWORTH SMITH, M.A. Second Edition. Maps, Plans, &c. Crown 8vo. 10*s.* 6*d.*

History of Ancient Egypt. By G. RAWLINSON, M.A. With Map and numerous Illustrations. 2 vols. 8vo. price 63*s.*

The Seventh Great Oriental Monarchy; or, a History of the Sassanians. By G. RAWLINSON, M.A. With Map and 95 Illustrations. 8vo. 28*s.*

The History of European Morals from Augustus to Charlemagne. By W. E. H. LECKY, M.A. 2 vols. crown 8vo. 16*s.*

History of the Rise and Influence of the Spirit of Rationalism in Europe. By W. E. H. LECKY, M.A. 2 vols. crown 8vo. 16*s.*

The History of Philosophy, from Thales to Comte. By GEORGE HENRY LEWES. Fifth Edition. 2 vols. 8vo. 32*s.*

A History of Classical Greek Literature. By the Rev. J. P. P. MAHAFFY, M.A. Crown 8vo. VOL. I. Poets, 7*s.* 6*d.* VOL. II. Prose Writers, 7*s.* 6*d.*

Zeller's Stoics, Epicureans, and Sceptics. Translated by the Rev. O. J. REICHEL, M.A. New Edition revised. Crown 8vo. 15*s.*

Zeller's Socrates & the Socratic Schools. Translated by the Rev. O. J. REICHEL, M.A. Second Edition. Crown 8vo. 10*s.* 6*d.*

Zeller's Plato & the Older Academy. Translated by S. FRANCES ALLEYNE and ALFRED GOODWIN, B.A. Crown 8vo. 18*s.*

Zeller's Pre-Socratic Schools; a History of Greek Philosophy from the Earliest Period to the time of Socrates. Translated by SARAH F. ALLEYNE. 2 vols. crown 8vo. 30*s.*

Zeller's Aristotle and the Elder Peripatetics. Translated by B. F. C. COSTELLOE, Balliol College, Oxford. Crown 8vo. [*In preparation.*

*** The above volume will complete the Authorised English Translation of Dr. ZELLER's Work on the Philosophy of the Greeks.

Epochs of Modern History. Edited by C. COLBECK, M.A.

Church's Beginning of the Middle Ages, 2*s.* 6*d.*
Cox's Crusades, 2*s.* 6*d.*
Creighton's Age of Elizabeth, 2*s.* 6*d.*
Gairdner's Lancaster and York, 2*s.* 6*d.*
——— **Puritan Revolution,** 2*s.* 6*d.*
——— **Thirty Years' War,** 2*s.* 6*d.*
Hale's Fall of the Stuarts, 2*s.* 6*d.*
Johnson's Normans in Europe, 2*s.* 6*d.*
Longman's Frederic the Great, 2*s.* 6*d.*
Ludlow's War of American Independence, 2*s.* 6*d.*
M'Carthy's Epoch of Reform, 1830-1850. 2*s.* 6*d.*
Morris's Age of Anne, 2*s.* 6*d.*
Seebohm's Protestant Revolution, 2/6.
Stubbs's Early Plantagenets, 2*s.* 6*d.*
Warburton's Edward III. 2*s.* 6*d.*

Epochs of Ancient History. Edited by the Rev. Sir G. W. COX, Bart. M.A. & C. SANKEY, M.A.

Beesly's Gracchi, Marius & Sulla, 2*s.* 6*d.*
Capes's Age of the Antonines, 2*s.* 6*d.*
——— **Early Roman Empire,** 2*s.* 6*d.*
Cox's Athenian Empire, 2*s.* 6*d.*
——— **Greeks & Persians,** 2*s.* 6*d.*
Curteis's Macedonian Empire, 2*s.* 6*d.*
Ihne's Rome to its Capture by the Gauls, 2*s.* 6*d.*
Merivale's Roman Triumvirates, 2*s.* 6*d.*
Sankey's Spartan & Theban Supremacies, 2*s.* 6*d.*
Smith's Rome and Carthage, 2*s.* 6*d.*

Creighton's Shilling History of England, introductory to 'Epochs of English History.' Fcp. 1*s.*

Epochs of English History. Edited by the Rev. MANDELL CREIGHTON, M.A. Fcp. 8vo. 5*s.*

Browning's Modern England, 1820-1874, 9*d.*
Cordery's Struggle against Absolute Monarchy, 1603-1688, 9*d.*
Creighton's (Mrs.) England a Continental Power, 1066-1216, 9*d.*
Creighton's (Rev. M.) Tudors and the Reformation, 1485-1603, 9*d.*
Rowley's Rise of the **People, 1215-1485,** price 9*d.*
Rowley's Settlement of the Constitution, 1688-1778, 9*d.*
Tancock's England during the American & European Wars, 1778-1820, 9*d.*
York-Powell's Early England to the Conquest, 1*s.*

The Student's Manual of Ancient History; the Political History, Geography and Social State of the Principal Nations of Antiquity. By W. COOKE TAYLOR, LL.D. Cr. 8vo. 7*s.* 6*d.*

The Student's Manual of Modern History; the Rise and Progress of the Principal European Nations. By W. COOKE TAYLOR, LL.D. Crown 8vo. 7*s.* 6*d.*

BIOGRAPHICAL WORKS.

The Correspondence of Robert Southey with Caroline Bowles. To which are added Correspondence with Shelley, and Southey's Dreams. Edited, with an Introduction, by EDWARD DOWDEN, LL.D. With a Portrait of Caroline Bowles. 8vo. price 14*s.*

The Life of Giuseppe Garibaldi. By J. THEODORE BENT. Crown 8vo. with Portrait, 7*s.* 6*d.*

Recollections of the Last Half-Century. By COUNT ORSI. With a Portrait of Napoleon III. and Four Woodcuts. Crown 8vo. price 7*s.* 6*d.*

The Marriages of the Bonapartes. By the Hon. D. A. BINGHAM. 2 vols. crown 8vo. 21*s.*

Reminiscences. By THOMAS CARLYLE. Edited by J. A. FROUDE, M.A. 2 vols. crown 8vo. 18*s.*

Autobiography. By JOHN STUART MILL. 8vo. 7*s.* 6*d.*

Felix Mendelssohn's Letters, translated by Lady WALLACE. 2 vols. crown 8vo. 5*s.* each.

The Life and Letters of Lord Macaulay. By his Nephew, G. OTTO TREVELYAN, M.P.

CABINET EDITION, 2 vols. crown 8vo. 12*s.*
POPULAR EDITION, 1 vol. crown 8vo. 6*s.*

William Law, Nonjuror and Mystic, a Sketch of his Life, Character, and Opinions. By J. H. OVERTON, M.A. Vicar of Legbourne. 8vo. 15*s.*

A Dictionary of General Biography. By W. L. R. CATES. Third Edition, revised throughout and completed; with nearly Four Hundred Memoirs and Notices of Persons recently deceased. 8vo. 28*s.*

Apologia pro Vitâ Suâ; Being a History of his Religious Opinions by JOHN HENRY NEWMAN, D.D. Crown 8vo. 6*s.*

Biographical Studies. By the late WALTER BAGEHOT, M.A. Fellow of University College, London. 8vo. 12*s.*

Leaders of Public Opinion in Ireland; Swift, Flood, Grattan, O'Connell. By W. E. H. LECKY, M.A. Crown 8vo. 7*s.* 6*d.*

Essays in Ecclesiastical Biography. By the Right Hon. Sir J. STEPHEN, LL.D. Crown 8vo. 7*s.* 6*d.*

Cæsar; a Sketch. By J. A. FROUDE, M.A. With Portrait and Map. 8vo. 16*s.*

Life of the Duke of Wellington. By the Rev. G. R. GLEIG, M.A. Crown 8vo. Portrait, 6*s.*

Memoirs of Sir Henry Havelock, K.C.B. By JOHN CLARK MARSHMAN. Crown 8vo. 3*s.* 6*d.*

Vicissitudes of Families. By Sir BERNARD BURKE, C.B. Two vols. crown 8vo. 21*s.*

Maunder's Treasury of Biography, in great part re-written, with above 1,600 additional Memoirs by W. L. R. CATES. Fcp. 8vo. 6*s.*

MENTAL and POLITICAL PHILOSOPHY.

Comte's System of Positive Polity, or Treatise upon Sociology. By various Translators. 4 vols. 8vo. £4.

De Tocqueville's Democracy in America, translated by H. REEVE. 2 vols. crown 8vo. 16*s.*

Analysis of the Phenomena of the Human Mind. By JAMES MILL. With Notes, Illustrative and Critical. 2 vols. 8vo. 28*s.*

On Representative Government. By JOHN STUART MILL. Crown 8vo. 2*s.*

On Liberty. By JOHN STUART MILL. Post 8vo. 7*s.* 6*d.* crown 8vo. 1*s.* 4*d.*

Principles of Political Economy. By JOHN STUART MILL. 2 vols. 8vo. 30*s.* or 1 vol. crown 8vo. 5*s.*

Essays on some Unsettled Questions of Political Economy. By JOHN STUART MILL. 8vo. 6*s.* 6*d.*

Utilitarianism. By JOHN STUART MILL. 8vo. 5*s.*

The Subjection of Women. By JOHN STUART MILL. Fourth Edition. Crown 8vo. 6*s.*

Examination of Sir William Hamilton's Philosophy. By JOHN STUART MILL. 8vo. 16*s.*

A System of Logic, Ratiocinative and Inductive. By JOHN STUART MILL. 2 vols. 8vo. 25*s.*

Dissertations and Discussions. By JOHN STUART MILL. 4 vols. 8vo. £2. 7*s.*

A Systematic View of the Science of Jurisprudence. By SHELDON AMOS, M.A. 8vo. 18*s.*

Path and Goal; a Discussion on the Elements of Civilisation and the Conditions of Happiness. By M. M. KALISCH, Ph.D. M.A. 8vo. price 12*s.* 6*d.*

The Law of Nations considered as Independent Political Communities. By Sir TRAVERS TWISS, D.C.L. 2 vols. 8vo. £1. 13*s.*

A Primer of the English Constitution and Government. By S. AMOS, M.A. Crown 8vo. 6*s.*

Fifty Years of the English Constitution, 1830-1880. By SHELDON AMOS, M.A. Crown 8vo. 10*s.* 6*d.*

Principles of Economical Philosophy. By H. D. MACLEOD, M.A. Second Edition, in 2 vols. VOL. I. 8vo. 15*s.* VOL. II. PART 1. 12*s.*

Lord Bacon's Works, collected & edited by R. L. ELLIS, M.A. J. SPEDDING, M.A. and D. D. HEATH. 7 vols. 8vo. £3. 13*s.* 6*d.*

Letters and Life of Francis Bacon, including all his Occasional Works. Collected and edited, with a Commentary, by J. SPEDDING. 7 vols. 8vo. £4. 4*s.*

The Institutes of Justinian; with English Introduction, Translation, and Notes. By T. C. SANDARS, M.A. 8vo. 18*s.*

The Nicomachean Ethics of Aristotle, translated into English by R. WILLIAMS, B.A. Crown 8vo. price 7*s.* 6*d.*

Aristotle's Politics, Books I. III. IV. (VII.) Greek Text, with an English Translation by W. E. BOLLAND, M.A. and Short Essays by A. LANG, M.A. Crown 8vo. 7*s.* 6*d.*

The Ethics of Aristotle; with Essays and Notes. By Sir A. GRANT, Bart. LL.D. 2 vols. 8vo. 32*s.*

Bacon's Essays, with Annotations. By R. WHATELY, D.D. 8vo. 10*s.* 6*d.*

An Introduction to Logic. By WILLIAM H. STANLEY MONCK, M.A. Prof. of Moral Philos. Univ. of Dublin. Crown 8vo. 5*s.*

Picture Logic; an Attempt to Popularise the Science of Reasoning. By A. J. SWINBURNE, B.A. Post 8vo. 5*s.*

Elements of Logic. By R. WHATELY, D.D. 8vo. 10*s.* 6*d.* Crown 8vo. 4*s.* 6*d.*

Elements of Rhetoric. By R. WHATELY, D.D. 8vo. 10*s.* 6*d.* Crown 8vo. 4*s.* 6*d.*

The Senses and the Intellect. By A. BAIN, LL.D. 8vo. 15*s.*

On the Influence of Authority in Matters of Opinion. By the late Sir. G. C. LEWIS, Bart. 8vo. 14*s.*

The Emotions and the Will. By A. BAIN, LL.D. 8vo. 15*s.*

Mental and Moral Science; a Compendium of Psychology and Ethics. By A. BAIN, LL.D. Crown 8vo. 10*s.* 6*d.*

An Outline of the Necessary Laws of Thought; a Treatise on Pure and Applied Logic. By W. THOMSON, D.D. Crown 8vo. 6*s.*

Essays in Political and Moral Philosophy. By T. E. CLIFFE LESLIE, Hon. LL.D. Dubl. of Lincoln's Inn, Barrister-at-Law. 8vo. 10*s.* 6*d.*

Hume's Philosophical Works. Edited, with Notes, &c. by T. H. GREEN, M.A. and the Rev. T. H. GROSE, M.A. 4 vols. 8vo. 56*s.* Or separately, Essays, 2 vols. 28*s.* Treatise on Human Nature, 2 vols. 28*s.*

MISCELLANEOUS & CRITICAL WORKS.

Studies of Modern Mind and Character at Several European Epochs. By JOHN WILSON. 8vo. 12*s.*

Selected Essays, chiefly from Contributions to the Edinburgh and Quarterly Reviews. By A. HAYWARD, Q.C. 2 vols. crown 8vo. 12*s.*

Short Studies on Great Subjects. By J. A. FROUDE, M.A. 3 vols. crown 8vo. 18*s.*

Literary Studies. By the late WALTER BAGEHOT, M.A. Fellow of University College, London. Second Edition. 2 vols. 8vo. with Portrait, 28*s.*

Manual of English Literature, Historical and Critical. By T. ARNOLD, M.A. Crown 8vo. 7*s.* 6*d.*

English Authors; Specimens of English Poetry and Prose from the earliest times to the present day; with references throughout to the above. Edited by T. ARNOLD, M.A. Crown 8vo. 7*s.* 6*d.*

The Wit and Wisdom of Benjamin Disraeli, Earl of Beaconsfield, collected from his Writings and Speeches. Crown 8vo. 6*s.*

The Wit and Wisdom of the Rev. Sydney Smith. Crown 8vo. 3*s.* 6*d.*

Lord Macaulay's Miscellaneous Writings:—

LIBRARY EDITION, 2 vols. 8vo. 21*s.*
PEOPLE'S EDITION, 1 vol. cr. 8vo. 4*s.* 6*d.*

Lord Macaulay's Miscellaneous Writings and Speeches. Student's Edition. Crown 8vo. 6*s.* Cabinet Edition, including Indian Penal Code, Lays of Ancient Rome, and other Poems. 4 vols. post 8vo. 24*s.*

Speeches of Lord Macaulay, corrected by Himself. Crown 8vo. 3*s.* 6*d.*

Selections from the Writings of Lord Macaulay. Edited, with Notes, by G. O. TREVELYAN, M.P. Crown. 8vo. 6*s.*

Miscellaneous Works of Thomas Arnold, D.D. late Head Master of Rugby School. 8vo. 7*s*. 6*d*.

German Home Life; a Series of Essays on the Domestic Life of Germany. Crown 8vo. 6*s*.

Realities of Irish Life. By W. STEUART TRENCH. Crown 8vo. 2*s*. 6*d*. boards, or 3*s*. 6*d*. cloth.

Apparitions; a Narrative of Facts. By the Rev. B. W. SAVILE, M.A. Second Edition. Crown 8vo. price 5*s*.

Evenings with the Skeptics; or, Free Discussion on Free Thinkers. By JOHN OWEN, Rector of East Anstey, Devon. 2 vols. 8vo. 32*s*.

Selected Essays on Language, Mythology, and Religion. By F. MAX MÜLLER, K.M. 2 vols. crown 8vo. 16*s*.

Lectures on the Science of Language. By F. MAX MÜLLER, K.M. 2 vols. crown 8vo. 16*s*.

Chips from a German Workshop; Essays on the Science of Religion, and on Mythology, Traditions & Customs. By F. MAX MÜLLER, K.M. 4 vols. 8vo. £1. 16*s*.

Language & Languages. A Revised Edition of Chapters on Language and Families of Speech. By F. W. FARRAR, D.D. F.R.S. Crown 8vo. 6*s*.

The Essays and Contributions of A. K. H. B. Uniform Cabinet Editions in crown 8vo.

Autumn Holidays, 3*s*. 6*d*.

Changed Aspects of Unchanged Truths, 3*s*. 6*d*.

Commonplace Philosopher, 3*s*. 6*d*.

Counsel and Comfort, 3*s*. 6*d*.

Critical Essays, 3*s*. 6*d*.

Graver Thoughts. 3 Series, 3*s*. 6*d*. each.

Landscapes, Churches, and Moralities, price 3*s*. 6*d*.

Leisure Hours in Town, 3*s*. 6*d*.

Lessons of Middle Age, 3*s*. 6*d*.

Our Little Life, 3*s*. 6*d*.

Present-Day Thoughts, 3*s*. 6*d*.

Recreations of a Country Parson, Three Series, 3*s*. 6*d*. each.

Seaside Musings, 3*s*. 6*d*.

Sunday Afternoons, 3*s*. 6*d*.

DICTIONARIES and OTHER BOOKS of REFERENCE.

One-Volume Dictionary of the English Language. By R. G. LATHAM, M.A. M.D. Medium 8vo. 14*s*.

Larger Dictionary of the English Language. By R. G. LATHAM, M.A. M.D. Founded on Johnson's English Dictionary as edited by the Rev. H. J. TODD. 4 vols. 4to. £7.

English Synonymes. By E. J. WHATELY. Edited by R. WHATELY, D.D. Fcp. 8vo. 3*s*.

Roget's Thesaurus of English Words and Phrases, classified and arranged so as to facilitate the expression of Ideas, and assist in Literary Composition. Revised and enlarged by the Author's Son, J. L. ROGET. Crown 8vo. 10*s*. 6*d*.

Handbook of the English Language. By R. G. LATHAM, M.A. M.D. Crown 8vo. 6*s*.

Contanseau's Practical Dictionary of the French and English Languages. Post 8vo. price 7*s*. 6*d*.

Contanseau's Pocket Dictionary, French and English, abridged from the Practical Dictionary by the Author. Square 18mo. 3*s.* 6*d.*

A Practical Dictionary of the German and English Languages. By Rev. W. L. BLACKLEY, M.A. & Dr. C. M. FRIEDLÄNDER. Post 8vo. 7*s.* 6*d.*

A New Pocket Dictionary of the German and English Languages. By F. W. LONGMAN, Ball. Coll. Oxford. Square 18mo. 5*s.*

Becker's Gallus; Roman Scenes of the Time of Augustus. Translated by the Rev. F. METCALFE, M.A. Post 8vo. 7*s.* 6*d.*

Becker's Charicles; Illustrations of the Private Life of the Ancient Greeks. Translated by the Rev. F. METCALFE, M.A. Post 8vo. 7*s.* 6*d.*

A Dictionary of Roman and Greek Antiquities. With 2,000 Woodcuts illustrative of the Arts and Life of the Greeks and Romans. By A. RICH, B.A. Crown 8vo. 7*s.* 6*d.*

A Greek-English Lexicon. By H. G. LIDDELL, D.D. Dean of Christchurch, and R. SCOTT, D.D. Dean of Rochester. Crown 4to. 36*s.*

Liddell & Scott's Lexicon, Greek and English, abridged for Schools. Square 12mo. 7*s.* 6*d.*

An English-Greek Lexicon, containing all the Greek Words used by Writers of good authority. By C. D. YONGE, M.A. 4to. 21*s.* School Abridgment, square 12mo. 8*s.* 6*d.*

A Latin-English Dictionary. By JOHN T. WHITE, D.D. Oxon. and J. E. RIDDLE, M.A. Oxon. Sixth Edition, revised. Quarto 21s.

White's Concise Latin-English Dictionary, for the use of University Students. Royal 8vo. 12*s.*

M'Culloch's Dictionary of Commerce and Commercial Navigation. Re-edited, with a Supplement shewing the Progress of British Commercial Legislation to the Year 1880, by HUGH G. REID. With 11 Maps and 30 Charts. 8vo. 63*s.*

Keith Johnston's General Dictionary of Geography, Descriptive, Physical, Statistical, and Historical; a complete Gazetteer of the World. Medium 8vo. 42*s.*

The Public Schools Atlas of Ancient Geography, in 28 entirely new Coloured Maps. Edited by the Rev. G. BUTLER, M.A. Imperial 8vo. or imperial 4to. 7*s.* 6*d.*

The Public Schools Atlas of Modern Geography, in 31 entirely new Coloured Maps. Edited by the Rev. G. BUTLER, M.A. Uniform, 5*s.*

ASTRONOMY and METEOROLOGY.

Outlines of Astronomy. By Sir J. F. W. HERSCHEL, Bart. M.A. Latest Edition, with Plates and Diagrams. Square crown 8vo. 12*s.*

The Moon, and the Condition and Configurations of its Surface. By E. NEISON, F.R.A.S. With 26 Maps and 5 Plates. Medium 8vo. price 31*s.* 6*d.*

Air and Rain; the Beginnings of a Chemical Climatology. By R. A. SMITH, F.R.S. 8vo. 24*s.*

Celestial Objects for Common Telescopes. By the Rev. T. W. WEBB, M.A. Fourth Edition, revised and adapted to the Present State of Sidereal Science; Map, Plate, Woodcuts. Crown 8vo. 9*s.*

The Sun; Ruler, Light, Fire, and Life of the Planetary System. By R. A. PROCTOR, B.A. With Plates & Woodcuts. Crown 8vo. 14*s.*

The Orbs Around Us; a Series of Essays on the Moon & Planets, Meteors & Comets, the Sun & Coloured Pairs of Suns. By R. A. PROCTOR, B.A. With Chart and Diagrams. Crown 8vo. 7*s.* 6*d.*

Other Worlds than Ours; The Plurality of Worlds Studied under the Light of Recent Scientific Researches. By R. A. PROCTOR, B.A. With 14 Illustrations. Crown 8vo. 10*s.* 6*d.*

The Moon; her Motions, Aspects, Scenery, and Physical Condition. By R. A. PROCTOR, B.A. With Plates, Charts, Woodcuts, and Lunar Photographs. Crown 8vo. 10*s.* 6*d.*

The Universe of Stars; Presenting Researches into and New Views respecting the Constitution of the Heavens. By R. A. PROCTOR, B.A. Second Edition, with 22 Charts (4 Coloured) and 22 Diagrams. 8vo. price 10*s.* 6*d.*

A New Star Atlas, for the Library, the School, and the Observatory, in 12 Circular Maps (with 2 Index Plates). By R. A. PROCTOR, B.A. Crown 8vo. 5*s.*

Larger Star Atlas, for the Library, in Twelve Circular Maps, with Introduction and 2 Index Plates. By R. A. PROCTOR, B.A. Folio, 15*s.* or Maps only, 12*s.* 6*d.*

Essays on Astronomy. A Series of Papers on Planets and Meteors, the Sun and Sun-surrounding Space, Stars and Star Cloudlets. By R. A. PROCTOR, B.A. With 10 Plates and 24 Woodcuts. 8vo. 12*s.*

NATURAL HISTORY and PHYSICAL SCIENCE.

Ganot's Elementary Treatise on Physics, Experimental and Applied, for the use of Colleges and Schools. Translated by E. ATKINSON, Ph.D. F.C.S. Tenth Edition, revised and enlarged; with 4 Coloured Plates and 844 Woodcuts. Large crown 8vo. 15*s.*

Ganot's Natural Philosophy for General Readers and Young Persons; a Course of Physics divested of Mathematical Formulæ and expressed in the language of daily life. Translated by E. ATKINSON, Ph.D. F.C.S. Fourth Edition, revised; with 2 Plates and 471 Woodcuts. Crown 8vo. 7*s.* 6*d.*

Professor Helmholtz' Popular Lectures on Scientific Subjects. Translated and edited by EDMUND ATKINSON, Ph.D. F.C.S. Professor of Chemistry &c. Staff College, Sandhurst. With a Preface by Professor TYNDALL, F.R.S. and 68 Woodcuts. 2 vols. crown 8vo. 15*s.* or separately, 7*s.* 6*d.* each.

Arnott's Elements of Physics or Natural Philosophy. Seventh Edition, edited by A. BAIN, LL.D. and A. S. TAYLOR, M.D. F.R.S. Crown 8vo. Woodcuts, 12*s.* 6*d.*

The Correlation of Physical Forces. By the Hon. Sir W. R. GROVE, F.R.S. &c. Sixth Edition, revised and augmented. 8vo. 15*s.*

A Treatise on Magnetism, General and Terrestrial. By H. LLOYD, D.D. D.C.L. &c. late Provost of Trinity College, Dublin. 8vo. 10*s.* 6*d.*

The Mathematical and other Tracts of the late James M'Cullagh, F.T.C.D. Professor of Natural Philosophy in the University of Dublin. Now first collected, and Edited by the Rev. J. H. JELLETT, B.D. and the Rev. S. HAUGHTON, M.D. Fellows of Trinity College, Dublin. 8vo. 15*s.*

Elementary Treatise on the Wave-Theory of Light. By H. LLOYD, D.D. D.C L. &c. late Provost of Trinity College, Dublin. 8vo. price 10s. 6d.

Fragments of Science. By JOHN TYNDALL, F.R.S. Sixth Edition, revised and augmented. 2 vols. crown 8vo. 16s.

Heat a Mode of Motion. By JOHN TYNDALL, F.R.S. Sixth Edition (Thirteenth Thousand), thoroughly revised and enlarged. Crown 8vo. 12s.

Sound. By JOHN TYNDALL, F.R.S. Fourth Edition, including Recent Researches. [*In the press.*

Essays on the Floating-Matter of the Air in relation to Putrefaction and Infection. By JOHN TYNDALL, F.R.S. With 24 Woodcuts. Crown 8vo. 7s. 6d.

Professor Tyndall's Lectures on Light, delivered in America in 1872 and 1873. With Portrait, Plate & Diagrams. Crown 8vo. 7s. 6d.

Professor Tyndall's Lessons in Electricity at the Royal Institution, 1875-6. With 58 Woodcuts. Crown 8vo. 2s. 6d.

Professor Tyndall's Notes of a Course of Seven Lectures on Electrical Phenomena and Theories, delivered at the Royal Institution. Crown 8vo. 1s. sewed, 1s. 6d. cloth.

Professor Tyndall's Notes of a Course of Nine Lectures on Light, delivered at the Royal Institution. Crown 8vo. 1s. swd., 1s. 6d. cloth.

Six Lectures on Physical Geography, delivered in 1876, with some Additions. By the Rev. SAMUEL HAUGHTON, F.R.S. M.D. D.C.L. With 23 Diagrams. 8vo. 15s.

An Introduction to the Systematic Zoology and Morphology of Vertebrate Animals. By A. MACALISTER, M.D. With 28 Diagrams. 8vo. 10s. 6d.

Text-Books of Science, Mechanical and Physical, adapted for the use of Artisans and of Students in Public and Science Schools. Small 8vo. with Woodcuts, &c.

Abney's Photography, 3s. 6d.
Anderson's (Sir John) Strength of Materials, 3s. 6d.
Armstrong's Organic Chemistry, 3s. 6d.
Ball's Elements of Astronomy, 6s.
Barry's Railway Appliances, 3s. 6d.
Bauerman's Systematic Mineralogy, 6s.
Bloxam's Metals, 3s. 6d.
Goodeve's Mechanics, 3s. 6d.
Gore's Electro-Metallurgy, 6s.
Griffin's Algebra & Trigonometry, 3/6.
Jenkin's Electricity & Magnetism, 3/6.
Maxwell's Theory of Heat, 3s. 6d.
Merrifield's Technical Arithmetic, 3s. 6d.
Miller's Inorganic Chemistry, 3s. 6d.
Preece & Sivewright's Telegraphy, 3/6.
Rutley's Study of Rocks, 4s. 6d.
Shelley's Workshop Appliances, 3s. 6d.
Thomé's Structural and Physiological Botany, 6s.
Thorpe's Quantitative Analysis, 4s. 6d.
Thorpe & Muir's Qualitative Analysis, price 3s. 6d.
Tilden's Chemical Philosophy, 3s. 6d.
Unwin's Machine Design, 3s. 6d.
Watson's Plane & Solid Geometry, 3/6.

The Comparative Anatomy and Physiology of the Vertebrate Animals. By RICHARD OWEN, F.R.S. With 1,472 Woodcuts. 3 vols. 8vo. £3. 13s. 6d.

Homes without Hands; a Description of the Habitations of Animals, classed according to their Principle of Construction. By the Rev. J. G. WOOD, M.A. With about 140 Vignettes on Wood. 8vo. 14s.

Wood's Strange Dwellings; a Description of the Habitations of Animals, abridged from 'Homes without Hands.' With Frontispiece and 60 Woodcuts. Crown 8vo. 7s. 6d. Popular Edition, 4to. 6d.

Wood's Insects at Home; a Popular Account of British Insects, their Structure, Habits, and Transformations. 8vo. Woodcuts, 14*s*.

Wood's Insects Abroad; a Popular Account of Foreign Insects, their Structure, Habits, and Transformations. 8vo. Woodcuts, 14*s*.

Wood's Out of Doors; a Selection of Original Articles on Practical Natural History. With 6 Illustrations. Crown 8vo. 7*s*. 6*d*.

Wood's Bible Animals; a description of every Living Creature mentioned in the Scriptures. With 112 Vignettes. 8vo. 14*s*.

The Sea and its Living Wonders. By Dr. G. HARTWIG. 8vo. with many Illustrations, 10*s*. 6*d*.

Hartwig's Tropical World. With about 200 Illustrations. 8vo. 10*s*. 6*d*.

Hartwig's Polar World; a Description of Man and Nature in the Arctic and Antarctic Regions of the Globe. Maps, Plates & Woodcuts. 8vo. 10*s*. 6*d*.

Hartwig's Subterranean World. With Maps and Woodcuts. 8vo. 10*s*. 6*d*.

Hartwig's Aerial World; a Popular Account of the Phenomena and Life of the Atmosphere. Map, Plates, Woodcuts. 8vo. 10*s*. 6*d*.

A Familiar History of Birds. By E. STANLEY, D.D. New Edition, revised and enlarged, with 160 Woodcuts. Crown 8vo. 6*s*.

Rural Bird Life; Essays on Ornithology, with Instructions for Preserving Objects relating to that Science. By CHARLES DIXON. With Coloured Frontispiece and 44 Woodcuts by G. Pearson. Crown 8vo. 7*s*. 6*d*.

Country Pleasures; the Chronicle of a Year, chiefly in a Garden. By GEORGE MILNER. Second Edition, with Vignette Title-page. Crown 8vo. price 6*s*.

The Note-book of an Amateur Geologist. By JOHN EDWARD LEE, F.G.S. F.S.A. &c. With numerous Woodcuts and 200 Lithographic Plates of Sketches and Sections. 8vo. 21*s*.

Rocks Classified and Described. By BERNHARD VON COTTA. An English Translation, by P. H. LAWRENCE, with English, German, and French Synonymes. Post 8vo. 14*s*.

The Geology of England and Wales; a Concise Account of the Lithological Characters, Leading Fossils, and Economic Products of the Rocks. By H. B. WOODWARD, F.G.S. Crown 8vo. Map & Woodcuts, 14*s*.

Keller's Lake Dwellings of Switzerland, and other Parts of Europe. Translated by JOHN E. LEE, F.S.A. F.G.S. With 206 Illustrations. 2 vols. royal 8vo. 42*s*.

Heer's Primæval World of Switzerland. Edited by JAMES HEYWOOD, M.A. F.R.S. With Map, 19 Plates, & 372 Woodcuts. 2 vols. 8vo. 12*s*.

The Puzzle of Life and How it Has Been Put Together; a Short History of Praehistoric Vegetable and Animal Life on the Earth. By A. NICOLS, F.R.G.S. With 12 Illustrations. Crown 8vo. 3*s*. 6*d*.

The Origin of Civilisation, and the Primitive Condition of Man; Mental and Social Condition of Savages. By Sir J. LUBBOCK, Bart. M.P. F.R.S. Fourth Edition, enlarged. 8vo. Woodcuts, 18*s*.

Light Science for Leisure Hours; Familiar Essays on Scientific Subjects, Natural Phenomena, &c. By R. A. PROCTOR, B.A. 2 vols. crown 8vo. 7*s*. 6*d*. each.

A Dictionary of Science, Literature, and Art. Re-edited by the Rev. Sir G. W. COX, Bart. M.A. 3 vols. medium 8vo. 63*s*.

Hullah's Course of Lectures on the History of Modern Music. 8vo. 8*s*. 6*d*.

Hullah's Second Course of Lectures on the Transition Period of Musical History. 8vo. 10*s*. 6*d*.

Loudon's Encyclopædia of Plants; the Specific Character, Description, Culture, History, &c. of all Plants found in Great Britain. With 12,000 Woodcuts. 8vo. 42*s*.

Loudon's Encyclopædia of Gardening; the Theory and Practice of Horticulture, Floriculture, Arboriculture & Landscape Gardening. With 1,000 Woodcuts. 8vo. 21*s*.

De Caisne & Le Maout's Descriptive and Analytical Botany. Translated by Mrs. HOOKER; edited and arranged by J. D. HOOKER, M.D. With 5,500 Woodcuts. Imperial 8vo. price 31*s*. 6*d*.

Rivers's Orchard-House; or, the Cultivation of Fruit Trees under Glass. Sixteenth Edition. Crown 8vo. with 25 Woodcuts, 5*s*.

The Rose Amateur's Guide. By THOMAS RIVERS. Latest Edition. Fcp. 8vo. 4*s*. 6*d*.

CHEMISTRY and PHYSIOLOGY.

Experimental Chemistry for Junior Students: By J. E. REYNOLDS, M.D. F.R.S. Professor of Chemistry, University of Dublin. Part I. Introductory. Fcp. 8vo. 1*s*. 6*d*.

Practical Chemistry; the Principles of Qualitative Analysis. By W. A. TILDEN, D.Sc. Lond. F.C S. Professor of Chemistry in Mason's College, Birmingham. Fcp. 8vo. 1*s*. 6*d*.

Miller's Elements of Chemistry, Theoretical and Practical. Re-edited, with Additions, by H. MACLEOD, F.C.S. 3 vols. 8vo.

PART I. CHEMICAL PHYSICS. 16*s*.
PART II. INORGANIC CHEMISTRY, 24*s*.
PART III. ORGANIC CHEMISTRY, 31*s*. 6*d*.

Annals of Chemical Medicine; including the Application of Chemistry to Physiology, Pathology, Therapeutics, Pharmacy, Toxicology, and Hygiene. Edited by J. L. W. THUDICHUM, M.D. VOL. I. 8vo. 14*s*.

Health in the House; Lectures on Elementary Physiology in its Application to the Daily Wants of Man and Animals. By Mrs. BUCKTON. Crown 8vo. Woodcuts, 2*s*.

A Dictionary of Chemistry and the Allied Branches of other Sciences. Edited by HENRY WATTS, F.C.S. 8 vols. medium 8vo. £12. 12*s*. 6*d*.

Third Supplement, completing the Record of Chemical Discovery to the year 1877. PART II. completion, is now ready, price 50*s*.

Practical Inorganic Chemistry. An Elementary Text-Book of Theoretical and Practical Inorganic Chemistry, designed chiefly for the use of Students of Science Classes connected with the Science and Art Department of the Committee of Council on Education. By W. JAGO, F.C.S. Science Master at Brighton College. With 37 Woodcuts. Fcp. 8vo. 2*s*.

The FINE ARTS and ILLUSTRATED EDITIONS.

Lord Macaulay's Lays of Ancient Rome, with Ivry and the Armada. With 41 Wood Engravings by G. Pearson from Original Drawings by J. R. Weguelin. Crown 8vo. 6*s*.

Lord Macaulay's Lays of Ancient Rome. With Ninety Illustrations engraved on Wood from Drawings by G. Scharf. Fcp. 4to. 21*s*. or imperial 16mo. 10*s*. 6*d*.

Notes on Foreign Picture Galleries. By C. L. EASTLAKE. F.R.I.B.A. Keeper of the National Gallery, London. Crown 8vo. fully Illustrated. [*In preparation.*

Vol. I. The Brera Gallery, Milan.
,, II. The Louvre, Paris.
,, III. The Pinacothek, Munich.

The Three Cathedrals dedicated to St. Paul in London. By W. LONGMAN, F.S.A. With Illustrations. Square crown 8vo. 21*s.*

Lectures on Harmony, delivered at the Royal Institution. By G. A. MACFARREN. 8vo. 12*s.*

Moore's Lalla Rookh. TENNIEL's Edition, with 68 Woodcut Illustrations. Crown 8vo. 10*s.* 6*d.*

Moore's Irish Melodies, MACLISE's Edition, with 161 Steel Plates. Super-royal 8vo. 21*s.*

Sacred and Legendary Art. By Mrs. JAMESON. 6 vols. square crown 8vo. £5. 15*s.* 6*d.*

Jameson's Legends of the Saints and Martyrs. With 19 Etchings and 187 Woodcuts. 2 vols. 31*s.* 6*d.*

Jameson's Legends of the Monastic Orders. With 11 Etchings and 88 Woodcuts. 1 vol. 21*s.*

Jameson's Legends of the Madonna. With 27 Etchings and 165 Woodcuts. 1 vol. 21*s.*

Jameson's History of the Saviour, His Types and Precursors. Completed by Lady EASTLAKE. With 13 Etchings and 281 Woodcuts. 2 vols. 42*s.*

The USEFUL ARTS, MANUFACTURES, &c.

The Elements of Mechanism. By T. M. GOODEVE, M.A. Barrister-at-Law. New Edition, re-written and enlarged, with 342 Woodcuts. Crown 8vo. 6*s.*

Railways and Locomotives; a Series of Lectures delivered at the School of Military Engineering, Chatham. *Railways*, by J. W. BARRY, M. Inst. C.E. *Locomotives*, by Sir F. J. BRAMWELL, F.R.S. M. Inst. C.E. With 228 Illustrations engraved on Wood. 8vo. price 21*s.*

The Engineer's Valuing Assistant. By H. D. HOSKOLD, Civil and Mining Engineer. 8vo. price 31*s.* 6*d.*

Gwilt's Encyclopædia of Architecture, with above 1,600 Woodcuts. Revised and extended by W. PAPWORTH. 8vo. 52*s.* 6*d.*

Lathes and Turning, Simple, Mechanical, and Ornamental. By W. H. NORTHCOTT. Second Edition, with 338 Illustrations. 8vo. 18*s.*

Industrial Chemistry; a Manual for Manufacturers and for Colleges or Technical Schools; a Translation of PAYEN's *Précis de Chimie Industrielle*. Edited, with Chapters on the Chemistry of the Metals, &c. by B. H. PAUL. With 698 Woodcuts. Medium 8vo. 42*s.*

The Theory of Strains in Girders and similar Structures, with Observations on the application of Theory to Practice, and Tables of the Strength and other Properties of Materials. By B. B. STONEY, M.A. M. Inst. C.E. Royal 8vo. with 5 Plates and 123 Woodcuts, 36*s.*

The British Navy: its Strength, Resources, and Administration. By Sir T. BRASSEY, K.C.B. M.P. M.A. In 6 vols. 8vo. VOLS. I. and II. with many Illustrations, 14*s.* or separately, VOL. I. 10*s.* 6*d.* VOL. II. price 3*s.* 6*d.*

A Treatise on Mills and Millwork. By the late Sir W. FAIRBAIRN, Bart. C.E. Fourth Edition, with 18 Plates and 333 Woodcuts. 1 vol. 8vo. 25*s.*

Useful Information for Engineers. By the late Sir W. FAIRBAIRN, Bart. C.E. With many Plates and Woodcuts. 3 vols. crown 8vo. 31*s.* 6*d.*

The Application of Cast and Wrought Iron to Building Purposes. By the late Sir W. FAIRBAIRN, Bart. C.E. With 6 Plates and 118 Woodcuts. 8vo. 16*s.*

Hints on Household Taste in Furniture, Upholstery, and other Details. By C. L. EASTLAKE. Fourth Edition, with 100 Illustrations. Square crown 8vo. 14*s.*

Handbook of Practical Telegraphy. By R. S. CULLEY, Memb. Inst. C.E. Seventh Edition. Plates & Woodcuts. 8vo. 16*s.*

The Marine Steam Engine. A Treatise for the use of Engineering Students and Officers of the Royal Navy. By RICHARD SENNETT, Chief Engineer, Royal Navy; First Assistant to Chief Engineer H.M. Dockyard, Devonport; late Instructor in Marine Engineering at the Royal Naval College. With numerous Illustrations and Diagrams. 8vo. price 21*s.*

A Treatise on the Steam Engine, in its various applications to Mines, Mills, Steam Navigation, Railways and Agriculture. By J. BOURNE, C.E. With Portrait, 37 Plates, and 546 Woodcuts. 4to. 42*s.*

Catechism of the Steam Engine, in its various Applications. By JOHN BOURNE, C.E. Fcp. 8vo. Woodcuts, 6*s.*

Handbook of the Steam Engine, a Key to the Author's Catechism of the Steam Engine. By J. BOURNE, C.E. Fcp. 8vo. Woodcuts, 9*s.*

Examples of Steam and Gas Engines of the most recent Approved Types as employed in Mines, Factories, Steam Navigation, Railways and Agriculture, practically described. By JOHN BOURNE, C.E. With 54 Plates and 356 Woodcuts. 4to. 70*s.*

Recent Improvements in the Steam Engine. By J. BOURNE, C.E. Fcp. 8vo. Woodcuts, 6*s.*

Ure's Dictionary of Arts, Manufactures, and Mines. Seventh Edition, re-written and enlarged by R. HUNT, F.R.S. assisted by numerous Contributors. With 2,604 Woodcuts. 4 vols. medium 8vo. £7. 7*s.*

Cresy's Encyclopædia of Civil Engineering, Historical, Theoretical, and Practical. With above 3,000 Woodcuts. 8vo. 25*s.*

Kerl's Practical Treatise on Metallurgy. Adapted from the last German Edition by W. CROOKES, F.R.S. &c. and E. RÖHRIG, Ph.D. 3 vols. 8vo. with 625 Woodcuts. £4. 19*s.*

Ville on Artificial Manures, their Chemical Selection and Scientific Application to Agriculture. Translated and edited by W. CROOKES, F.R.S. With 31 Plates. 8vo. 21*s.*

Mitchell's Manual of Practical Assaying. Fifth Edition, revised, with the Recent Discoveries incorporated, by W. CROOKES, F.R.S. Crown 8vo. Woodcuts, 31*s.* 6*d.*

The Art of Perfumery, and the Methods of Obtaining the Odours of Plants; the Growth and general Flower Farm System of Raising Fragrant Herbs; with Instructions for the Manufacture of Perfumes &c. By G. W. S. PIESSE, Ph.D. F.C.S. Fourth Edition, with 96 Woodcuts. Square crown 8vo. 21*s.*

Loudon's Encyclopædia of Gardening; the Theory and Practice of Horticulture, Floriculture, Arboriculture & Landscape Gardening. With 1,000 Woodcuts. 8vo. 21*s.*

Loudon's Encyclopædia of Agriculture; the Laying-out, Improvement, and Management of Landed Property; the Cultivation and Economy of the Productions of Agriculture. With 1,100 Woodcuts. 8vo. 21*s.*

RELIGIOUS and MORAL WORKS.

An Introduction to the Study of the New Testament, Critical, Exegetical, and Theological. By the Rev. S. DAVIDSON, D.D. LL.D. New Edition, thoroughly revised by the Author. 2 vols. 8vo. 30*s.*

History of the Papacy During the Reformation. By M. CREIGHTON, M.A. late Fellow of Merton College, Oxford. 2 vols. 8vo. VOL. I. the Great Schism—the Council of Constance, 1378–1418. VOL. II. the Council of Basel—the Papal Restoration, 1418–1464. [*In the press.*

A History of the Church of England; Pre-Reformation Period. By the Rev. T. P. BOULTBEE, LL.D. 8vo. 15*s.*

Sketch of the History of the Church of England to the Revolution of 1688. By T. V. SHORT, D.D. Crown 8vo. 7*s.* 6*d.*

The English Church in the Eighteenth Century. By C. J. ABBEY, late Fellow of Univ. Coll. Oxon. and J. H. OVERTON, late Scholar of Lincoln Coll. Oxon. 2 vols. 8vo. 36*s.*

An Exposition of the 39 Articles, Historical and Doctrinal. By E. H. BROWNE, D.D. Bishop of Winchester. Eleventh Edition. 8vo. 16*s.*

A Commentary on the 39 Articles, forming an Introduction to the Theology of the Church of England. By the Rev. T. P. BOULTBEE, LL.D. New Edition. Crown 8vo. 6*s.*

Sermons preached mostly in the Chapel of Rugby School by the late T. ARNOLD, D.D. Collective Edition, revised by the Author's Daughter, Mrs. W. E. FORSTER. 6 vols. crown 8vo. 30*s.* or separately, 5*s.* each.

Historical Lectures on the Life of Our Lord Jesus Christ. By C. J. ELLICOTT, D.D. 8vo. 12*s.*

The Eclipse of Faith; or a Visit to a Religious Sceptic. By HENRY ROGERS. Fcp. 8vo. 5*s.*

Defence of the Eclipse of Faith. By H. ROGERS. Fcp. 8vo. 3*s.* 6*d.*

Nature, the Utility of Religion, and Theism. Three Essays by JOHN STUART MILL. 8vo. 10*s.* 6*d.*

A Critical and Grammatical Commentary on St. Paul's Epistles. By C. J. ELLICOTT, D.D. 8vo. Galatians, 8*s.* 6*d.* Ephesians, 8*s.* 6*d.* Pastoral Epistles, 10*s.* 6*d.* Philippians, Colossians, & Philemon, 10*s.* 6*d.* Thessalonians, 7*s.* 6*d.*

Conybeare & Howson's Life and Epistles of St. Paul. Three Editions, copiously illustrated.

Library Edition, with all the Original Illustrations, Maps, Landscapes on Steel, Woodcuts, &c. 2 vols. 4to. 42*s.*

Intermediate Edition, with a Selection of Maps, Plates, and Woodcuts. 2 vols. square crown 8vo. 21*s.*

Student's Edition, revised and condensed, with 46 Illustrations and Maps. 1 vol. crown 8vo. 7*s.* 6*d.*

Smith's Voyage & Shipwreck of St. Paul; with Dissertations on the Life and Writings of St. Luke, and the Ships and Navigation of the Ancients. Fourth Edition, revised by the Author's Son, with all the Original Illustrations. Cr. 8vo. 7*s.* 6*d.*

A Handbook to the Bible, or, Guide to the Study of the Holy Scriptures derived from Ancient Monuments and Modern Exploration. By F. R. CONDER, and Lieut. C. R. CONDER, R.E. Third Edition, Maps. Post 8vo. 7*s.* 6*d.*

Bible Studies. By M. M. KALISCH, Ph.D. PART I. *The Prophecies of Balaam.* 8vo. 10*s.* 6*d.* PART II. *The Book of Jonah.* 8vo. price 10*s.* 6*d.*

Historical and Critical Commentary on the Old Testament; with a New Translation. By M. M. KALISCH, Ph.D. Vol. I. Genesis, 8vo. 18*s.* or adapted for the General Reader, 12*s.* Vol. II. Exodus, 15*s.* or adapted for the General Reader, 12*s.* Vol. III. Leviticus, Part I. 15*s.* or adapted for the General Reader, 8*s.* Vol. IV. Leviticus, Part II. 15*s.* or adapted for the General Reader, 8*s.*

The Four Gospels in Greek, with Greek-English Lexicon. By JOHN T. WHITE, D.D. Oxon. Square 32mo. 5*s.*

Ewald's History of Israel. Translated from the German by J. E. CARPENTER, M.A. with Preface by R. MARTINEAU, M.A. 5 vols. 8vo. 63*s.*

Ewald's Antiquities of Israel. Translated from the German by H. S. SOLLY, M.A. 8vo. 12*s.* 6*d.*

The New Man and the Eternal Life; Notes on the Reiterated Amens of the Son of God. By A. JUKES. Crown 8vo. 6*s.*

The Types of Genesis, briefly considered as revealing the Development of Human Nature. By A. JUKES. Crown 8vo. 7*s.* 6*d.*

The Second Death and the Restitution of all Things; with some Preliminary Remarks on the Nature and Inspiration of Holy Scripture. By A. JUKES. Crown 8vo. 3*s.* 6*d.*

Supernatural Religion; an Inquiry into the Reality of Divine Revelation. Complete Edition, thoroughly revised. 3 vols. 8vo. 36*s.*

Lectures on the Origin and Growth of Religion, as illustrated by the Religions of India. By F. MAX MÜLLER, K.M. 8vo. 10*s.* 6*d.*

Introduction to the Science of Religion, Four Lectures delivered at the Royal Institution; with Essays on False Analogies and the Philosophy of Mythology. By F. MAX MÜLLER, K.M. Crown 8vo. 10*s.* 6*d.*

The Gospel for the Nineteenth Century. Fourth Edition. 8vo. price 10*s.* 6*d.*

Passing Thoughts on Religion. By Miss SEWELL. Fcp. 8vo. price 3*s.* 6*d.*

Preparation for the Holy Communion; the Devotions chiefly from the works of Jeremy Taylor. By Miss SEWELL. 32mo. 3*s.*

Private Devotions for Young Persons. Compiled by ELIZABETH M. SEWELL, Author of 'Amy Herbert' &c. 18mo. 2*s.*

Bishop Jeremy Taylor's Entire Works; with Life by Bishop Heber. Revised and corrected by the Rev. C. P. EDEN. 10 vols. £5. 5*s.*

Hymns of Praise and Prayer. Corrected and edited by Rev. JOHN MARTINEAU, LL.D. Crown 8vo. 4*s.* 6*d.* 32mo. 1*s.* 6*d.*

Spiritual Songs for the Sundays and Holidays throughout the Year. By J. S. B. MONSELL, LL.D. Fcp. 8vo. 5*s.* 18mo. 2*s.*

Christ the Consoler; a Book of Comfort for the Sick. By ELLICE HOPKINS. Second Edition. Fcp. 8vo. 2*s.* 6*d.*

Lyra Germanica; Hymns translated from the German by Miss C. WINKWORTH. Fcp. 8vo. 5*s.*

Hours of Thought on Sacred Things; Two Volumes of Sermons. By JAMES MARTINEAU, D.D. LL.D. 2 vols. crown 8vo. 7*s.* 6*d.* each.

Endeavours after the Christian Life; Discourses. By JAMES MARTINEAU, D.D. LL.D. Fifth Edition. Crown 8vo. 7*s.* 6*d.*

The Pentateuch & Book of Joshua Critically Examined. By J. W. COLENSO, D.D. Bishop of Natal. Crown 8vo. 6*s.*

Lectures on the Pentateuch and the Moabite Stone; with Appendices. By J. W. COLENSO, D.D. Bishop of Natal. 8vo. 12*s.*

TRAVELS, VOYAGES, &c.

Sunshine and Storm in the East, or Cruises to Cyprus and Constantinople. By Lady BRASSEY. Cheaper Edition, with 2 Maps and 114 Illustrations engraved on Wood. Cr. 8vo. 7*s*. 6*d*.

A Voyage in the 'Sunbeam,' our Home on the Ocean for Eleven Months. By Lady BRASSEY. Cheaper Edition, with Map and 65 Wood Engravings. Crown 8vo. 7*s*. 6*d*. School Edition, fcp. 2*s*. Popular Edition, 4to. 6*d*.

Eight Years in Ceylon. By Sir SAMUEL W. BAKER, M.A. Crown 8vo. Woodcuts, 7*s*. 6*d*.

The Rifle and the Hound in Ceylon. By Sir SAMUEL W. BAKER, M.A. Crown 8vo. Woodcuts, 7*s*. 6*d*.

Sacred Palmlands; or, the Journal of a Spring Tour in Egypt and the Holy Land. By A. G. WELD. Crown 8vo. 7*s*. 6*d*.

Wintering in the Riviera; with Notes of Travel in Italy and France, and Practical Hints to Travellers. By WILLIAM MILLER, S.S.C. Edinburgh. With 12 Illustrations. Post 8vo. 7*s*. 6*d*.

San Remo and the Western Riviera, climatically and medically considered. By A. HILL HASSALL, M.D. Map and Woodcuts. Crown 8vo. 10*s*. 6*d*.

Himalayan and Sub-Himalayan Districts of British India, their Climate, Medical Topography, and Disease Distribution. By F. N. MACNAMARA, M.D. With Map and Fever Chart. 8vo. 21*s*.

The Alpine Club Map of Switzerland, with parts of the Neighbouring Countries, on the scale of Four Miles to an Inch. Edited by R. C. NICHOLS, F.R.G.S. 4 Sheets in Portfolio, 42*s*. coloured, or 34*s*. uncoloured.

Enlarged Alpine Club Map of the Swiss and Italian Alps, on the Scale of 3 English Statute Miles to 1 Inch, in 8 Sheets, price 1*s*. 6*d*. each.

The Alpine Guide. By JOHN BALL, M.R.I.A. Post 8vo. with Maps and other Illustrations :—

The Eastern Alps, 10*s*. 6*d*.

Central Alps, including all the Oberland District, 7*s*. 6*d*.

Western Alps, including Mont Blanc, Monte Rosa, Zermatt, &c. Price 6*s*. 6*d*.

On Alpine Travelling and the Geology of the Alps. Price 1*s*. Either of the Three Volumes or Parts of the 'Alpine Guide' may be had with this Introduction prefixed, 1*s*. extra.

WORKS of FICTION.

The Hughenden Edition of the Novels and Tales of the Earl of Beaconsfield, K.G. from Vivian Grey to Endymion. With Maclise's Portrait of the Author, a later Portrait on Steel from a recent Photograph, and a Vignette to each volume. To the last volume, *Endymion*, is appended a brief Memoir of the Life and Political Career of the Earl of Beaconsfield. Eleven Volumes, crown 8vo. bound in cloth extra, 42*s*.

Novels and Tales. By the Right Hon. the EARL of BEACONSFIELD, K.G. The Cabinet Edition. Eleven Volumes, crown 8vo. 6*s*. each.

The Novels and Tales of the Right Hon. the Earl of Beaconsfield, K.G. Modern Novelist's Library Edition, complete in Eleven Volumes, crown 8vo. price 22*s*. boards, or 27*s*. 6*d*. cloth.

Buried Alive; or, Ten Years of Penal Servitude in Siberia. By FEDOR DOSTOYEFFSKY. Translated from the German by MARIE VON THILO. Fourth Edition. Post 8vo. 6*s*.

Whispers from Fairy-land. By the Right Hon. E. H. KNATCHBULL-HUGESSEN, M.P. With 9 Illustrations. Crown 8vo. 3*s*. 6*d*.

Higgledy-Piggledy; or, Stories for Everybody and Everybody's Children. By the Right Hon. E. H. KNATCHBULL-HUGESSEN, M.P.. With 9 Illustrations. Uniform, 3*s*. 6*d*.

Stories and Tales. By ELIZABETH M. SEWELL. Cabinet Edition, in Ten Volumes, crown 8vo. price 3*s*. 6*d*. each, in cloth extra, with gilt edges:—

Amy Herbert.	Ivors.
Gertrude.	Katharine Ashton.
The Earl's Daughter	Margaret Percival.
Experience of Life.	Laneton Parsonage.
Cleve Hall.	Ursula.

The Modern Novelist's Library. Each work complete in itself, price 2*s*. boards, or 2*s*. 6*d*. cloth :—

By Earl BEACONSFIELD, K.G.

Endymion.

Lothair.	**Henrietta Temple.**
Coningsby.	**Contarini Fleming, &c.**
Sybil.	**Alroy, Ixion, &c.**
Tancred.	**The Young Duke, &c.**
Venetia.	**Vivian Grey.**

By ANTHONY TROLLOPE.

Barchester Towers.
The Warden.

By Major WHYTE-MELVILLE.

Digby Grand.	**Good for Nothing.**
General Bounce.	**Holmby House.**
Kate Coventry.	**The Interpreter.**
The Gladiators.	**Queen's Maries.**

By the Author of 'The Rose Garden.'

Unawares.

By the Author of 'Mlle. Mori.'

The Atelier du Lys.
Mademoiselle Mori.

By Various Writers.

Atherstone Priory.
The Burgomaster's Family.
Elsa and her Vulture.
The Six Sisters of the Valleys.

Novels and Tales by the Right Honourable the Earl of Beaconsfield, K.G. Modern Novelist's Library Edition, complete in Eleven Volumes, crown 8vo. cloth extra, gilt edges, price 33*s*.

POETRY and THE DRAMA.

Poetical Works of Jean Ingelow. New Edition, reprinted, with Additional Matter, from the 23rd and 6th Editions of the two volumes respectively; with 2 Vignettes. 2 vols. fcp. 8vo. 12*s*.

Faust. From the German of GOETHE. By T. E. WEBB, LL.D. Reg. Prof. of Laws & Public Orator in the Univ. of Dublin. 8vo. 12*s*. 6*d*.

Goethe's Faust. A New Translation, chiefly in Blank Verse; with a complete Introduction and copious Notes. By JAMES ADEY BIRDS, B.A. F.G.S. Large crown 8vo. 12*s*. 6*d*.

Goethe's Faust. The German Text, with an English Introduction and Notes for Students. By ALBERT M. SELSS, M.A. Ph.D. Prof. of German in the Univ. of Dublin. Cr. 8vo. 5*s*.

Lays of Ancient Rome; with Ivry and the Armada. By LORD MACAULAY. 16mo. 3*s*. 6*d*.

The Poem of the Cid: a Translation from the Spanish, with Introduction and Notes. By JOHN ORMSBY. Crown 8vo. 5*s*.

Festus, a Poem. By PHILIP JAMES BAILEY. 10th Edition, enlarged & revised. Crown 8vo. 12*s*. 6*d*.

The 'Festus' Birthday-Book. Fcp. 8vo. 3*s*. 6*d*.

The Iliad of Homer, Homometrically translated by C. B. CAYLEY. 8vo. 12*s*. 6*d*.

Bowdler's Family Shakspeare. Genuine Edition, in 1 vol. medium 8vo. large type, with 36 Woodcuts, 14*s*. or in 6 vols. fcp. 8vo. 21*s*.

The Æneid of Virgil. Translated into English Verse. By J. CONINGTON, M.A. Crown 8vo. 9*s*.

Southey's Poetical Works, with the Author's last Corrections and Additions. Medium 8vo. with Portrait, 14*s*.

RURAL SPORTS, HORSE and CATTLE MANAGEMENT, &c.

Blaine's Encyclopædia of Rural Sports; Complete Accounts, Historical, Practical, and Descriptive, of Hunting, Shooting, Fishing, Racing, &c. With 600 Woodcuts. 8vo. 21*s*.

A Book on Angling; or, Treatise on the Art of Fishing in every branch; including full Illustrated Lists of Salmon Flies. By FRANCIS FRANCIS. Post 8vo. Portrait and Plates, 15*s*.

Wilcocks's Sea-Fisherman: comprising the Chief Methods of Hook and Line Fishing, a glance at Nets, and remarks on Boats and Boating. Post 8vo. Woodcuts, 12*s*. 6*d*.

The Fly-Fisher's Entomology. By ALFRED RONALDS. With 20 Coloured Plates. 8vo. 14*s*.

Horses and Roads; or, How to Keep a Horse Sound on his Legs. By FREE-LANCE. Second Edition. Crown 8vo. 6*s*.

Horses and Riding. By GEORGE NEVILE, M.A. With 31 Illustrations. Crown 8vo. 6*s*.

Horses and Stables. By Major-General Sir F. FITZWYGRAM, Bart. Second Edition, revised and enlarged; with 39 pages of Illustrations containing very numerous Figures. 8vo. 10*s*. 6*d*.

Youatt on the Horse. Revised and enlarged by W. WATSON, M.R.C.V.S. 8vo. Woodcuts, 7*s*. 6*d*.

Youatt's Work on the Dog. Revised and enlarged. 8vo. Woodcuts, 6*s*.

The Dog in Health and Disease. By STONEHENGE. Third Edition, with 78 Wood Engravings. Square crown 8vo. 7*s*. 6*d*.

The Greyhound. By STONEHENGE. Revised Edition, with 25 Portraits of Greyhounds, &c. Square crown 8vo. 15*s*.

Stables and Stable Fittings. By W. MILES. Imp. 8vo. with 13 Plates, 15*s*.

The Horse's Foot, and How to keep it Sound. By W. MILES. Imp. 8vo. Woodcuts, 12*s*. 6*d*.

A Plain Treatise on Horse-shoeing. By W. MILES. Post 8vo. Woodcuts, 2*s*. 6*d*.

Remarks on Horses' Teeth, addressed to Purchasers. By W. MILES. Post 8vo. 1*s*. 6*d*.

A Treatise on the Diseases of the Ox; being a Manual of Bovine Pathology specially adapted for the use of Veterinary Practitioners and Students. By J. H. STEEL, M.R.C.V.S. F.Z.S. With 2 Plates and 116 Woodcuts. 8vo. 15*s*.

WORKS of UTILITY and GENERAL INFORMATION.

Maunder's Biographical Treasury. Latest Edition, reconstructed and partly re-written, with above 1,600 additional Memoirs, by W. L. R. CATES. Fcp. 8vo. 6*s*.

Maunder's Treasury of Natural History; or, Popular Dictionary of Zoology. Revised and corrected Edition. Fcp. 8vo. with 900 Woodcuts, 6*s*.

Maunder's Treasury of Geography, Physical, Historical, Descriptive, and Political. Edited by W. HUGHES, F.R.G.S. With 7 Maps and 16 Plates. Fcp. 8vo. 6*s*.

Maunder's Historical Treasury; Introductory Outlines of Universal History, and Separate Histories of all Nations. Revised by the Rev. Sir G. W. COX, Bart. M.A. Fcp. 8vo. 6*s*.

Maunder's Treasury of Knowledge and Library of Reference; comprising an English Dictionary and Grammar, Universal Gazetteer, Classical Dictionary, Chronology, Law Dictionary, Synopsis of the Peerage, Useful Tables, &c. Fcp. 8vo. 6*s*.

Maunder's Scientific and Literary Treasury; a Popular Encyclopædia of Science, Literature, and Art. Latest Edition, partly re-written, with above 1,000 New Articles, by J. Y. JOHNSON. Fcp. 8vo. 6*s*.

The Treasury of Botany, or Popular Dictionary of the Vegetable Kingdom; with which is incorporated a Glossary of Botanical Terms. Edited by J. LINDLEY, F.R.S. and T. MOORE, F.L.S. With 274 Woodcuts and 20 Steel Plates. Two Parts, fcp. 8vo. 12*s*.

The Treasury of Bible Knowledge; being a Dictionary of the Books, Persons, Places, Events, and other Matters of which mention is made in Holy Scripture. By the Rev. J. AYRE, M.A. Maps, Plates & Woodcuts. Fcp. 8vo. 6*s*.

A Practical Treatise on Brewing; with Formulæ for Public Brewers & Instructions for Private Families. By W. BLACK. 8vo. 10*s*. 6*d*.

The Theory of the Modern Scientific Game of Whist. By W. POLE, F.R.S. Thirteenth Edition. Fcp. 8vo. 2*s*. 6*d*.

The Correct Card; or, How to Play at Whist; a Whist Catechism. By Major A. CAMPBELL-WALKER, F.R.G.S. Fourth Edition. Fcp. 8vo. 2*s*. 6*d*.

The Cabinet Lawyer; a Popular Digest of the Laws of England, Civil, Criminal, and Constitutional. Twenty-Fifth Edition, corrected and extended. Fcp. 8vo. 9*s*.

Chess Openings. By F.W. LONGMAN, Balliol College, Oxford. New Edition. Fcp. 8vo. 2*s*. 6*d*.

Pewtner's Comprehensive Specifier; a Guide to the Practical Specification of every kind of Building-Artificer's Work. Edited by W. YOUNG. Crown 8vo. 6*s*.

Modern Cookery for Private Families, reduced to a System of Easy Practice in a Series of carefully-tested Receipts. By ELIZA ACTON. With 8 Plates and 150 Woodcuts. Fcp. 8vo. 6*s*.

Food and Home Cookery. A Course of Instruction in Practical Cookery and Cleaning, for Children in Elementary Schools. By Mrs. BUCKTON. Woodcuts. Crown 8vo. 2*s*.

The Ventilation of Dwelling Houses and the Utilisation of Waste Heat from Open Fire-Places, &c. By F. EDWARDS, Jun. Second Edition. With numerous Lithographic Plates, comprising 106 Figures. Royal 8vo. 10*s*. 6*d*.

Hints to Mothers on the Management of their Health during the Period of Pregnancy and in the Lying-in Room. By THOMAS BULL, M.D. Fcp. 8vo. 2*s*. 6*d*.

The Maternal Management of Children in Health and Disease. By THOMAS BULL, M.D. Fcp. 8vo. 2*s*. 6*d*.

American Farming and Food. By FINLAY DUN, Special Correspondent for the 'Times.' Crown 8vo. 10*s*. 6*d*.

The Farm Valuer. By JOHN SCOTT, Land Valuer. Crown 8vo. 5*s*.

Rents and Purchases; or, the Valuation of Landed Property, Woods, Minerals, Buildings, &c. By JOHN SCOTT. Crown 8vo. 6*s*.

Economic Studies. By the late WALTER BAGEHOT, M.A. Fellow of Univ. Coll. London. Edited by R. H. HUTTON. 8vo. 10*s*. 6*d*.

Economics for Beginners By H. D. MACLEOD, M.A. Small crown 8vo. 2*s*. 6*d*.

The Elements of Economics. By H. D. MACLEOD, M.A. In 2 vols. VOL. I. crown 8vo. 7*s*. 6*d*.

The Elements of Banking. By H. D. MACLEOD, M.A. Fourth Edition. Crown 8vo. 5*s*.

The Theory and Practice of Banking. By H. D. MACLEOD, M.A. 2 vols. 8vo. 26*s*.

The Resources of Modern Countries; Essays towards an Estimate of the Economic Position of Nations and British Trade Prospects. By ALEX. WILSON. 2 vols. 8vo. 24*s*.

The Patentee's Manual; a Treatise on the Law and Practice of Letters Patent, for the use of Patentees and Inventors. By J. JOHNSON, Barrister-at-Law; and J. H. JOHNSON, Assoc. Inst. C.E. Solicitor and Patent Agent. Fourth Edition, enlarged. 8vo. price 10*s*. 6*d*.

Willich's Popular Tables Arranged in a New Form, giving Information &c. equally adapted for the Office and the Library. Ninth Edition, edited by M. MARRIOTT, Barrister. Crown 8vo. 10*s*.

INDEX.

Spottiswoode & Co. Printers, New-street Square, London.